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Site proposal

VOLUME 3

GEOLOGY AND TUNNELING

SITE PROPOSAL
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VOLUME 3

GEOLOGY AND TUNNELING

SITE PROPOSAL

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STATE OF
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COMANCHE
BASIN

VOLUME 3

GEOLOGY AND TUNNELING

Comanche Basin geology is exceptionally well-suited to this project.

Flat topography permits a cost-efficient, shallow tunnel with a nearly ideal tunnel profile.

Horizontally bedded sedimentary rock near the surface provides uniform tunnel and structure support with no settlement problem.

Area seismicity is low.
Faulting is minor and inactive.

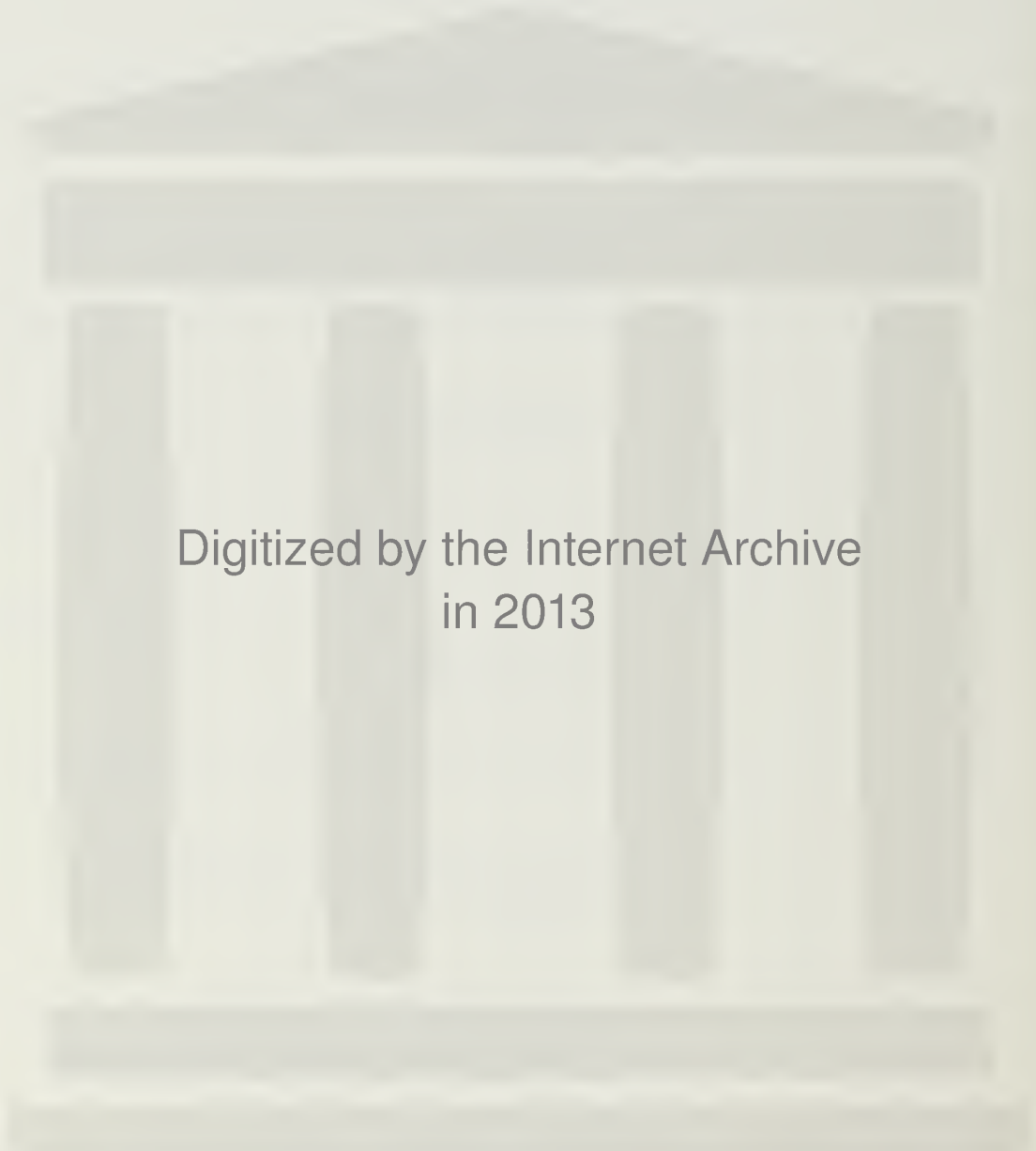
There is no potential for liquefaction.

Competent, soft rock is ideal for rapid tunnel advance rates.

Cut-and-cover sections are easily rippable.

Ground water conditions present no significant problem for underground construction.

All excavated material is useable for roads and structural fill resulting in no net spoil.



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GEOLOGY AND TUNNELING

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3.1 GENERAL

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GEOLOGY AND TUNNELING

3.1 GENERAL

3.1.1 Proposed Location

The proposed location, as shown on Figure 3.1-1, is in the south-central portion of Montana within 20 highway miles of the city of Billings. The tunnel ring is predominantly in the northwest corner of Yellowstone County, which contains about 20 miles (40 percent) of the ring length and 75 percent of the offered land. The remainder of the ring and land areas extend into the three adjoining counties of Stillwater to the west, Golden Valley, and Musselshell to the north.

The site is in the Comanche Basin. The perimeter of the basin is 300 to 400 feet higher than the low points in the center. Elevations around the ring will generally vary from 3850 feet on the east to 4150 feet on the west. The tunnel elevation is primarily controlled by the elevations of the Burlington Northern Railroad and State Highway 3, which passes over the northern and southern arc regions of the tunnel. The site is generally flat with some gently rolling terrain, and appears to be an ideal location for the facility.

Some low points contain transient ponds during wet seasons; however, the climate tends to be arid in this region, and water will not be a problem because the basin-like topography channels runoff towards the basin center and away from the collider ring. The land is used for dryland farming or grazing, and because of low rainfall, large crops are generated only about once every three years. There is very little overburden, and rock outcrops are visible around the site. The entire tunnel will be founded in bedrock.

The proposed detailed location is shown on Figure 3.1-3, in the map folder. These are maps prepared from 7.5-minute USGS quadrangle maps (Scale 1 inch = 2,000 feet). There are six maps comprising two quadrangles each which cover the site.

The proposed center of the collider ring is located at Longitude 108°51'14" and Latitude 46°00'54", which is in the NE 1/4 of the NW 1/4 of Sec. 15, T3N, R23E, Broadview, East Quadrangle, MPM.

The long axis lies in a general north-south direction with a bearing calculated from the quadrangle map of 26 degrees, 31 minutes and 8 seconds west of true north.

The Burlington Northern Railroad and State Highway 3 run parallel through the site and cross the ring at its southeast and northeast quadrants. Broadview, the only town within the ring, is adjacent to the railroad within 3 miles of the northern-most ring perimeter. High voltage power transmission lines cross the ring in an east-west and north-west direction.

The profile of the ring has been established so that the two long sides containing the experimental halls and campus area are level. The west side is 280 feet higher than the east side to accommodate terrain differences and provide for shallower excavations for the west structures. The north and south tunnel arcs follow the same sloping plane, which is skewed in plan 10.8 degrees to the longitudinal collider axis. The vertical slope and vertical curves of the arcs meet SSC design criteria. The profile is shown on Figure 3.1-4, in the map folder.

The campus cluster is located on the east side of the ring closest to State Highway 3 to provide for shorter access to Billings and the airport. The terrain in the campus area is flatter than on the west side and is more suitable for these facilities.

The site is crossed by many county roads with gravel surfaces. This road network is ideal for access to the many points around the ring where facilities are located. Improvements to the roads are expected during the construction phase.

A number of alternative collider locations were examined. The proposed location appears to be nearly optimum. Perhaps some further refinement could be made; however, it was concluded that within the time constraints any change would be limited to movement of the ring center less than a half mile. It was further concluded that the USGS maps are not accurate enough to justify further optimization of the ring location.

3.1.2 Proposed Profile

The ring has been positioned in a tilted plane with two foldlines running parallel to each on each side of the longitudinal axis of the collider, and skewed 10.8 degrees to the axis. The skew angle is controlled by the railroad and highway orientation and the skewing was done to optimize tunnel depths. The long sides are level with the west side 280 feet higher than the east side to accommodate terrain differences. The centerline of tunnel on the west side is at elevation 4015 feet and the east side is 3735. The northern and southern arc areas lie along a single sloping plane with a maximum profile grade of 0.5 degrees (0.873 percent slope). The elevation of the arc areas is controlled by the elevation of the Burlington Northern Railroad which passes over the tunnel in these areas. The railroad is generally level across the site passing over the tunnel at elevation 3785 on the south, and 3800 on the north end. Setting the tunnel at 3735 feet provides a minimum 50 feet of cover above the centerline of the tunnel at these points so that surface land acquisition could be avoided at the highway and railroad.

The intent of the layout was to keep access structures as shallow as possible. To accommodate this, a million-foot radius of curvature criteria was used for the transition between the level and sloping tunnel section, keeping the transition as short as possible.

The overall slope of a plane passing across the short axis perpendicular to the long sides (from F5 to F10) is 0.20 degrees (0.353 percent slope). This configuration provides a nearly ideal profile.

The large-scale profile is shown on Figure 3.1-4. A smaller-scale version of the profile is in Section 3.3 of the text. The profiles are plotted with an exaggerated vertical scale of 40 times the horizontal scale on Figure 3.1-4, and 125 times on the small profile shown on Figure 3.3-1. This gives a distorted visual appearance to the gently rolling topography of the area.

Figure 3.1-2 is a depth histogram for the entire tunnel length. About 6 percent of the ring has less than 50 feet of cover, 50 percent less than 120 feet, and no point greater than 290 feet of depth. The deepest access structure is 255 feet deep and the average of the nine others is 115 feet. This profile will provide for ideal opportunities for cut-and-cover construction, where men and materials can be moved in and out of the tunnel at various points around the ring. It will also keep the excavations and depths of access structures and experimental halls to a minimum while minimizing impacts on farming and grazing.

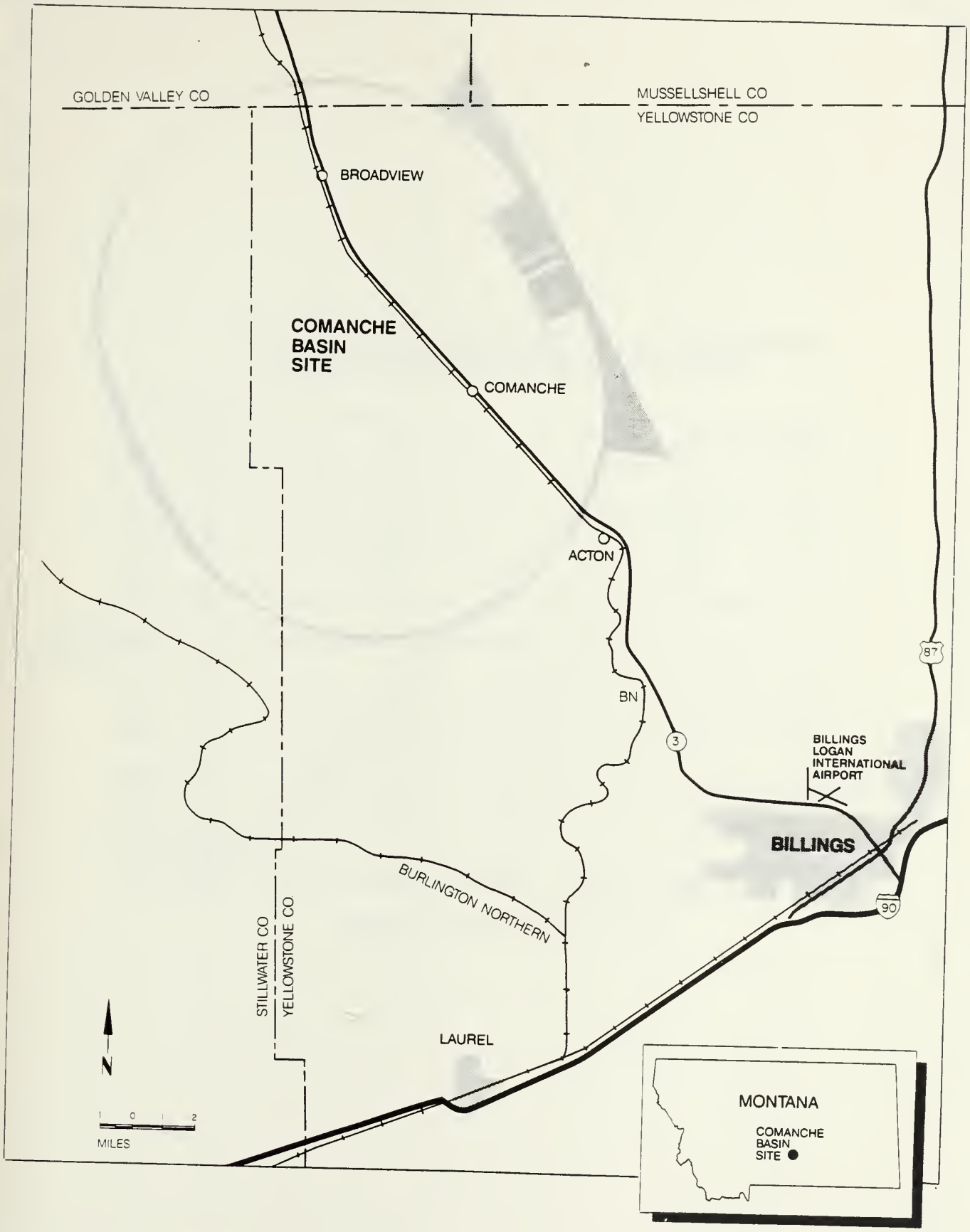

Figure 3.1-1 COMANCHE BASIN SSC SITING AREA

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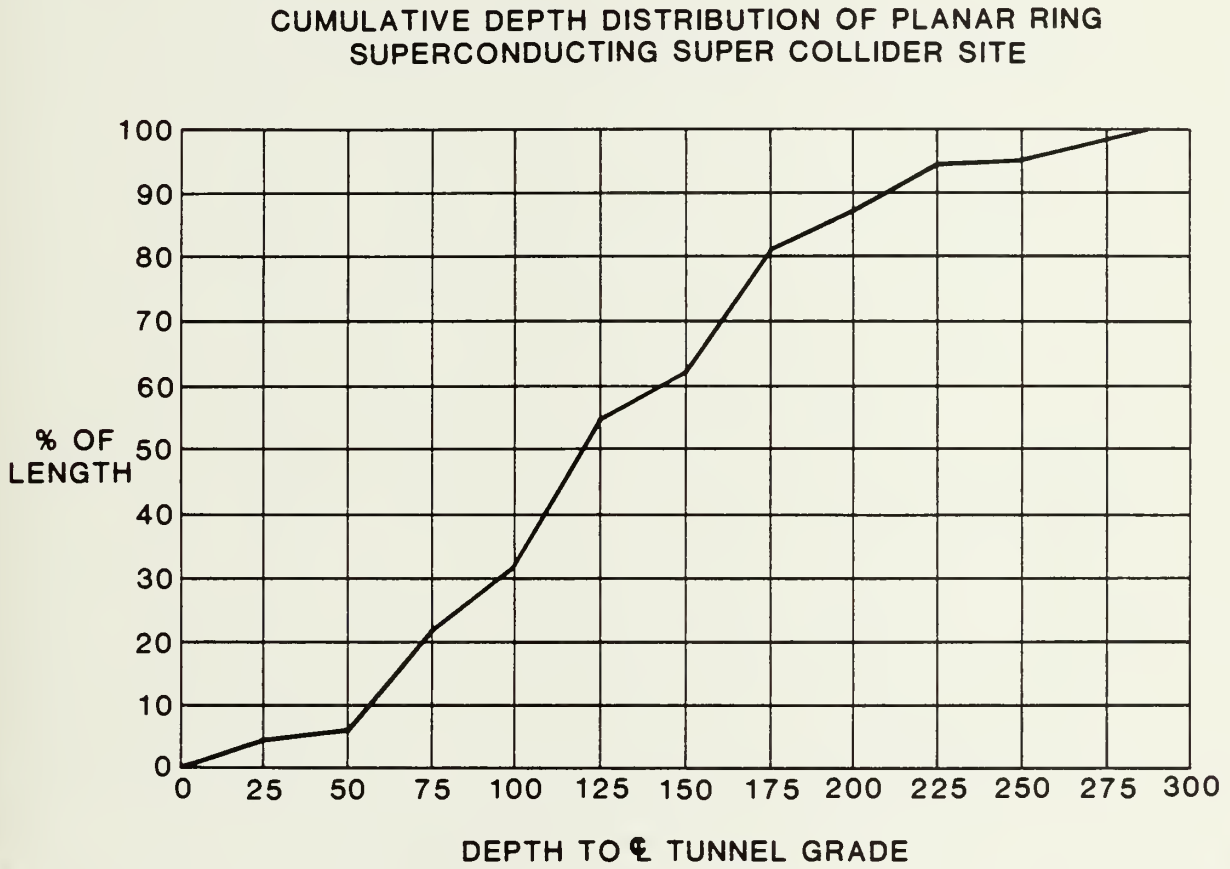


Figure 3.1-2
COMANCHE BASIN SSC TUNNEL DEPTH DISTRIBUTION

3.2 GEOLOGY

In this section, the regional geology of east central Montana is discussed as well as the geology of the Comanche Basin. The geologic conditions specific to the proposed ring location and structures are also presented.

Within this section, soils are classified in accordance with ASTM D2487 Classification of Soils for Engineering Purposes. Rock units are described in accordance with AGI terminology, except that the alternative silty or argillaceous sandstone is used rather than wacke, since the former is more universally understood in this area than the latter.

The regional geology has been characterized based on published maps and literature, and on the experience of Northern Engineering and Testing, Inc., which has done extensive work in the region. At the site, data was taken from ten new borings drilled into distinct formations around the ring as well as site observations, material testing and data taken from older borings when Montana Power Company transmission structures were routed. Logs from wells were reviewed. The site was visited, and materials tested and evaluated by Alfred J. Hendron Jr., Ph.D., and personnel from Northern Engineering and Testing, Inc., and Stone & Webster Engineering Corp. The data and evaluations presented in this volume are based on substantial factual information and considerable experience and technical expertise.

3.2.1 Regional Geology

The proposed site lies at the western edge of the Great Plains, within a finger of plains about 100 miles wide inserted between the Snowy Mountains to the north, the Pryor Mountains to the south and the Crazy Mountains to the west, as shown on Figure 3.2-1 in the map pocket. The site is located about 50 miles from each of these uplifted areas, at an elevation of about 4000 feet.

Mid-to-late Cretaceous and early Tertiary marine sedimentary units, including silty and/or argillaceous sandstone, siltstone and claystone, are exposed in the area. These units have been moderately folded and locally faulted by the adjacent mountain building during Cretaceous and early Tertiary time (Freeze and Cherry, 1979; Johns, 1982).

As the regional uplift occurred during the Cretaceous/Tertiary period, higher energy sedimentation began to dominate. As a result, most of the rock units in this area are characterized by high sand-silt content rather than the high silt-clay content characteristic of the same units further east.

The Yellowstone River, about 20 miles to the south of the proposed site, cuts through the various upper Cretaceous and lower Tertiary rock units, and at Billings, the river bed is in the Middle Cretaceous Cody shale, with the Eagle formation creating the surrounding cliffs.

More specifically, the Comanche Basin is an unglaciated, closed basin. The basin is surrounded by low rolling hills, the erosional remnants of the east limb of the Big Coulee-Hailstone Dome, a broad northwest-southeast trending anticline, and the uplifted resistant sandstone units along the en echelon shear zone known as the Lake Basin Fault Zone, forming the southwestern boundary of the proposed site (Alpha and Fanshawe, 1954; Freeze and Cherry, 1979; Sonnenberg, 1956).

Hydrocarbon deposits, primarily natural gas, are present near the center of the Big Coulee-Hailstone Dome to the west, but no major petroleum production or other deposits have been discovered through extrapolation within the proposed site area.

There are no major streams in the basin, and alluvial deposits are thin to absent, except in the center of Comanche Flat, where clay, sand and silt have been deposited by seasonal runoff into the basin.

3.2.2 Site Geology

Around the ring, alluvial cover is thin, and colluvium from the underlying bedrock is the principal soil. Bedrock units generally dip from 0 to 20 degrees east, along the exposed east limb of the Big Coulee-Hailstone Anticline, except along the southwest portion of the site, where en echelon faulting along the Lake Basin Fault Zone has tilted, uplifted and/or dropped some of the rock units.

Near-surface and exposed bedrock units are late Cretaceous and early Tertiary sedimentary formations, including Eagle, Claggett, Judith River, Bearpaw and Lennep, all Cretaceous; and the Hell Creek-Tullock formations, which are boundary formations including both Cretaceous and Tertiary, without an obvious contact. These are shown in Figure 3.2-2 and at a 10 to 1 vertically distorted cross-section in Figure 3.2-3. Photographs of each of the exposed geological formations are provided as Figure 3.2-4. Near the center of Comanche Flat there is a significant accumulation of quaternary alluvium. The bedrock formations and alluvium are described below from oldest to youngest (Lawlor, 1956).

- Eagle; Keu: This formation contains three distinct units (a) an upper thin-bedded silty sandstone containing rounded, black chert pebbles within a fine to medium grained sand matrix, (b) a middle thin-bedded argillaceous sandstone with interbedded carbonaceous shale seams, and (c) a lower massive, medium grained silty sandstone. The latter unit forms cliffs (rimrocks) around local basins, notably at Billings, but exposures of this unit are limited in the site area. The sandstone is massive and friable; upper units are more friable and weather readily. The Eagle is a locally limited aquifer. The stratigraphic thickness of the Eagle formation in the site area is 250 to 400 feet.

- Claggett, Kcl: This formation includes dark grey to grey claystone and sandy claystone interbedded with thin argillaceous sandstone seams. It is generally capped with a persistent argillaceous sandstone unit, while the lower units contain calcareous concretions. Below the cap unit, most of the claystone and sandstone beds are soft and weather readily. The stratigraphic thickness in the site area is 200 to 300 feet.

- Judith River, Kjr: This formation consists of interbedded buff, tan and white silty sandstones, and light gray to black sandy claystone interbeds near the center of the formation. Sandstone units are commonly crossbedded and tuffaceous. Claystone units contain shell and plant fragment fossils and lignite lenses. The upper sandstone units are moderately resistant and form ridges and low hills on the west side of the site. The sandstone units are low-volume aquifers in the site area. The stratigraphic thickness of the Judith River formation is 250 to 400 feet.

- Bearpaw, Kb: This formation is primarily grey to black, massive marine claystone, with some thin, calcareous argillaceous sandstone units in the upper 50 feet of formation. Some of the claystone units, in the lower 50 feet of the formation have significant bentonite content, (Berg, 1969; Knechtel and Patterson, 1956) and the claystone in these units is expansive with decomposition and moisture (and/or oxygen) increase. The claystone has high sulfate content. It weathers readily forming low areas with saline seeps. The claystone is impermeable, except along local fractures and gypsum-filled fissures. At this location, the Bearpaw formation contains significantly more sand and silt than farther east or northeast. The Bearpaw formation varies from 150 to 350 feet thick in the site area.

- Lennep, Kl: This formation is well cemented, tuffaceous silty sandstone, including a fairly massive lower unit, a middle andesitic unit and an upper tuffaceous unit. It is moderately friable and weather resistant and forms a ridge east of Broadview. The Lennep is about 60 feet thick in the site area, and is stratigraphically equivalent to the Fox Hills formation elsewhere in Montana.

- Hell Creek/Tullock Formations, Khc/Tt: These formations include tan to yellowish, cross-bedded silty and/or argillaceous sandstone units interbedded with thin bluish-gray sandy claystone units. Sandstones are lenticular and discontinuous, and significant carbonaceous layers are present in both formations. Rock units are friable, weather readily and exposures are mostly concealed with colluvium. In the site area, this formation is approximately 75 percent sandstone and 25 percent sandy claystone and/or siltstone. Although these two formations are the boundary between Cretaceous and Tertiary, the contact is generally gradational and uncertain. Within the site area, these formations are more than 500 feet total thickness.

- Quaternary Alluvium, Qal: Alluvial deposits consist primarily of clay, silt and sand, weathered and decomposed from the nearby soft bedrock units, transported, and deposited along the surface drainages and low areas of the basin. The thickest alluvial deposits are inside of the ring area, where adjacent streams have deposited sediments into the undrained Comanche Flat area to reported depths of up to 75 feet. These soils are soft, and generally saturated.

3.2.3 Tunnel Profile

Nearly all of the tunnel lies within upper Cretaceous and Lower Tertiary sandstone, siltstone, and claystone bedrock units. The geotechnical characteristics of these materials are discussed in detail in other portions of this volume. The following narrative describes, section by section, the material in which the tunnel will be constructed. This information is shown on Figure 3.1-4 in the map folder. The narrative begins at the east campus complex at F10 and proceeds clockwise. Stationing starts with F10 as zero and proceeds clockwise. For station locations, see large scale profile Figure 3.1-4.

- F10 to E1 (0 to 27000) - In this reach, the tunnel will be about 100 to 200 feet below the ground surface in the Hell Creek and Tullock formations.

At this elevation these interbedded sandstone, siltstone and claystone units are very dense and contain occasional carbonaceous layers. Sandstone units contain significant amounts of fine silt and some clay, and are, therefore, relatively impermeable. Only small groundwater seepage is expected, primarily confined to a few of the cleaner sandstone lenses and some of the carbonaceous units. The rock units are sound and relatively unfractured, except for the bedding fracture, which dips about 4 to 6 degrees easterly. Rock units will be about 75 percent sandstone and 25 percent sandy claystone or siltstone.

- F1 area (27,000 to 28,400) - Here the tunnel will encounter the Lennep formation, which is stratigraphically equivalent to the Fox Hills further east. This medium-grained, crossbedded, massive sandstone unit contains significant amounts of silt and clay and is relatively dense. Whereas the sandstone is somewhat friable in outcrops, at tunnel depth it will be very competent.

- F1 - E2 (28,400 to 49,400) - The tunnel, which will be from 50 to 120 feet deep in this reach, will pass through the Bearpaw formation, which is silty and/or sandy claystone in the upper 50 feet of the formation. With depth, the clay content increases and the lower 50 feet of the formation contains thin bentonite beds. The formation is fairly massive claystone, but contains fissures in the more plastic zones. The bedding dips about 5 degrees easterly. The claystone units are relatively impermeable, and the formation in this area is an aquiclude. Moisture content decreases with depth, as does expansion potential. A moisture profile is attached to the log of Boring DH-9 in Appendix 3A. It is apparent at the site that the expansion potential is decreased to a minimum at depths below 25 feet and claystone is at moisture equilibrium, having the properties of soft rock, below 40 feet depth. Most of the tunnel will be constructed in this zone of the formation. The claystone will be relatively easy to excavate at tunnel depth.

- E2 to E3 (49,400 to 70,200) - In this reach the tunnel, which will be about 15 to 120 feet below the surface, will encounter the Judith River formation. While there are some thin claystone interbeds near the center of the formation, it is primarily medium-grained, massive, friable sandstone. Fractures are slight to moderate, except for the bedding fractures, which dip about 5 degrees easterly. These sandstone units yield the principal domestic water in the area, yet flows are small, on the order of 1 to 3 gallons/square foot/day, from the most pervious units. Excavation of the sandstone units is expected to be relatively easy.

- E3 to F3 (70,200 to 93,200) - Within this section of tunnel, at depths of 50 to 150 feet, the Claggett formation will be encountered. The formation consists of interbedded sandstone and sandy claystone units which are moderately fractured, but competent at tunnel depth. Within this reach, the units have been locally folded in a broad anticline, so that bedding dip varies from about 5 degrees easterly to horizontal to 3 degrees westerly. Due to the significant clay content of the units, permeability is low and groundwater flows are expected to be slight. The rock units at tunnel depth will be abut 40 percent sandstone and 60 percent sandy claystone or siltstone.

- F3 to F4 (93,200 to 119,000) – In this section, the tunnel is at depths varying from about 50 to 180 feet below the surface and will encounter the Judith River formation, similar to that described from E2 to E3, except that sandstone will be more fractured, and groundwater flows may increase in and adjacent to the fault zone between E4 and E5.

- F4 to K3 (119,000 to 130,800) – Within this reach, which is bounded by two fault zones, the tunnel alignment varies from 100 feet below the surface to the ground surface and will encounter Bearpaw formation, as described from 28,400 to 49,400 (F1 – E2), in the first half of the section. The second half will encounter some alluvium and colluvium, derived from the underlying Judith River formation, and consisting of Sandy, Lean Clay (CL), and weathered Judith River formation, which will be friable, fractured sandstone. The last half of the section is one of the three small areas within which the tunnel is at or near the ground surface.

- K3 to K5 (130,800 to 148,000) – Within this reach, the tunnel depth varies from 15 to 200 feet below the surface. The section is bounded by two faults and there are several more faults within the section. Bedrock units are repetitive sandstone and claystone units of the Judith River and Claggett formations as previously described.

  Fracturing is significant within 50 to 100 feet of each fault, and groundwater flows may increase slightly, although surface evidence indicates only small seepages in this area. At one location, 5000 feet ahead of K3, the tunnel will traverse a layer of alluvium. The section is in a valley floor, about 500 feet wide, where the Silty and Sandy CLAY (CL) alluvium is up to 25 feet thick.

- K5 to K6 (148,000 to 153,400) - In this reach, bounded by two fault zones, the tunnel will encounter the Eagle formation in the first half and the Claggett formation in the second half. The Eagle formation, in this section, is thick to medium bedded sandstone, with some claystone layers. Some light groundwater flow may be present in the upper portion of the Eagle. The sandstone is fractured, but competent. The Claggett formation will be as described from E3 to F3.

- K6 to F6 (153,400 to 178,400) - The tunnel, at depths of 110 to 175 feet, will encounter the lower, massive sandstone of the Eagle formation. From our test boring DH-3, it is evident that the sandstone will be very competent, dense, and relatively unfractured. Permeability is low, and groundwater flows of 1 to 4 gallons/square foot/day are expected from the more pervious zones.

- F6 to F7 (178,400 to 209,000) - Within this reach, depth to the tunnel varies from about 20 feet to 270 feet. The interbedded sandstone and claystone units of the Claggett formation, dipping about 5 to 10 degrees easterly, will be encountered in the tunnel. The formation is relatively competent and has generally low to very low permeability. The formation will be similar to that described from E3 to F3, except that it is expected to be less fractured and more competent.

- F7 to E8 (209,000 to 223,000) - The tunnel in this section at a maximum depth of 280 feet, will encounter the full thickness of the Judith River sandstone. Bedding dips about 6 to 15 degrees east. The formation contains some interbedded claystone units, but will be mostly massive sandstone. Within this section, groundwater flows on the order of 1 to 3 gallons/square foot/day will be encountered in the more pervious units. The water is expected to be fair quality, except near the contact with the Bearpaw, where the sulfate content will increase.

- F8 area (223,000 to 225,000) - As the tunnel crosses beneath the railroad at the north end of the ring, it will encounter the Bearpaw formation, with similar characteristics as described in the F1 area.

- F8 area (225,000 to 225,800) - In this section the tunnel will encounter the Lennep formation, similar to the reach at F1. Bedding dips about 20 to 25 degrees easterly.

- F8 to F10 (225,800 - 283,000) - Within this final section, at depths of about 60 to 225 feet, the tunnel booster ring and experimental hall areas will encounter the interbedded sandstone, siltstone and claystone units of the Hell Creek/Tullock formation as described in the sections from F10 to E1. Bedding dips vary from about 25 degrees at the north end of the section to about 6 degrees at the south end.

3.2.3.1 **Recap of Profile**

In summary, the tunnel will encounter the various formations as follows:

1.	Hell Creek/Tullock and Lennep	15.8 miles
2.	Bearpaw	5.3 miles
3.	Judith River	13.3 miles
4.	Claggett	13.3 miles
5.	Eagle	5.3 miles

Regarding rock units, the tunnel will be in the following:

Sandstone	68 percent
Sandy Claystone/Siltstone	21 percent
Claystone	7 percent
Bentonitic Claystone (lower 50 feet of Bearpaw)	4 percent

The ring has been located such that no major structures are founded on potentially expansive materials.

3.2.4 Geologic Features

Design and construction of the ring and appurtenances must consider the geologic conditions. The more important of these conditions are as follows:

- Varying rock characteristics - Construction of tunnel and surface structures will encounter six different formations, each having several different rock units. Tunnel and structure design and construction must anticipate these conditions and accommodate the variation in physical and engineering properties, which may change from one rock type (for example claystone) to another (such as sandstone) within a few tens of feet as the construction crosses formational or unit boundaries. For tunnel construction, additional support may be required at formation contacts. A typical range of values for allowable bearing capacity for structures founded on these materials is discussed in Section 3.5 (Northern Engineering & Testing 1957-87). Where the lower zones of the Bearpaw formation are exposed or near surface, the decomposed claystone has significant expansion potential. At depths below about 25 feet (tunnel depth), the claystone has low expansion potential, but will air-slake with prolonged exposure. Construction must be specified and executed to avoid prolonged exposure of these units and avoid significant changes in moisture content.

- Fault zones - Rock units within about 100 feet of each of the several en echelon faults are relatively closely fractured. Within these zones, tunnel design should anticipate some increased groundwater flow (this is discussed further in Geohydrology) as well as additional support.

- Slope stability - Temporary and permanent cut slope stability of the rock units is variable. Typical design slopes for the rock types along the tunnel alignment are discussed in Section 3.5 (Net 1957-87).

- Soil and water corrosivity - Sulfate content of most of the claystone and groundwater within the claystone units is in a range normally considered deleterious to normal strength concrete and must be considered in design of concrete structures. This can be accomplished by relatively simple adjustments of the concrete mix proportions.

3.2.5 Soil Conditions

As previously stated, only limited, local accumulations of soil are present, overlying bedrock along the ring alignment. Most of the surface construction will involve excavated bedrock material, but some of the thin soils will also be involved. These soils are primarily colluvial, derived from decomposition of the underlying bedrock units with transportation on the order of 0 to 10 miles. Many of the characteristics of the bedrock units, therefore, are reflected in the soils. Since sandstone and interbedded sandstone-claystone, make up the majority of the bedrock material, most of the soils are Silty or Clayey SAND (SM or SC). Locally, however, there are accumulations of Lean CLAY and Sandy CLAY (CL), and along the center of Comanche Flat, where the Bearpaw formation is exposed, Fat CLAY (CH). These moderate to highly plastic clays have moisture-sensitive shear strength and generally poor subgrade support properties. Use of the Fat CLAY (CH) should be avoided, except where impermeable materials are needed (NET 1957-87).

With the exception of the Fat CLAY (CH) soil, most of the site soils are fair to good construction materials with fair to good subgrade support properties.

B0787001

LEGEND

Fault, dashed where inferred; ball on downthrown side

Strike and dip of bedding

Contact

Anticlinal Axis

Boring Location

Previous boring location (for transmission line)

SYMBOL - FORMATION

- Qal - Quaternary Alluvium
- Tfu - Fort Union
- Khc/Tt - Hell Creek/Tullock
- Kl - Lennep
- Kb - Bearpaw
- Kjr - Judith River
- Kcl - Claggett
- Keu - Eagle

1 0 1 2
MILES

STATE OF MONTANA 9/2/87

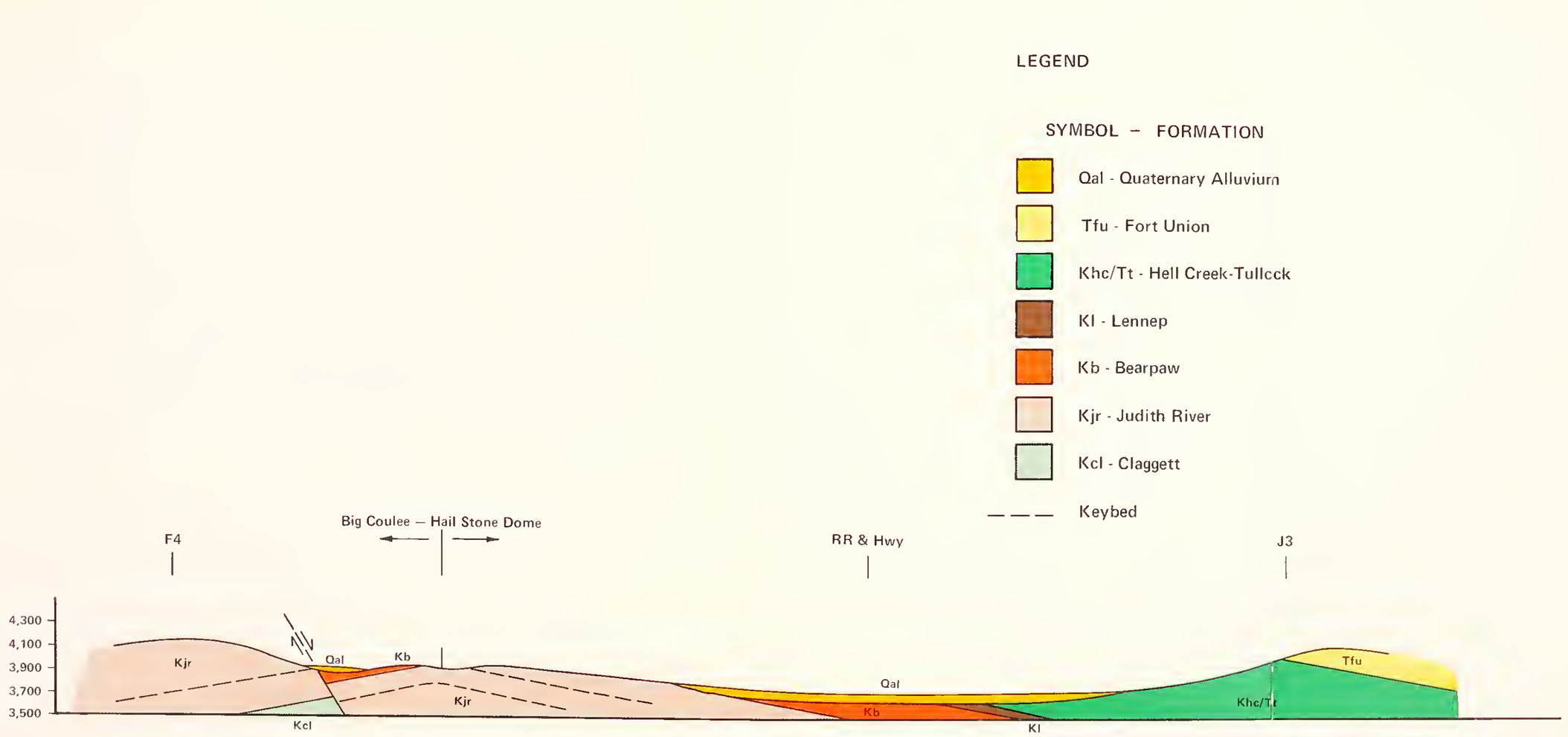
Figure 3.2-2
COMANCHE BASIN SSC SITE GEOLOGY

B0787002

LEGEND

SYMBOL – FORMATION

- Qal - Quaternary Alluvium
- Tfu - Fort Union
- Khc/Tt - Hell Creek-Tullock
- Kl - Lennep
- Kb - Bearpaw
- Kjr - Judith River
- Kcl - Claggett
- — — — Keybed



SCALE
1" = 10,000' Horz.
1" = 1,000' Vert.

GEOLOGIC CROSS-SECTION A-A

STATE OF MONTANA 9/2/87

Figure 3.2-3
GEOLOGIC CROSS SECTION

Figure 3.2-4 SITE GEOLOGICAL FORMATIONS

PHOTO 1
Outcrop of Eagle Sandstone representative of Eagle Formation encountered from E6 to F6 along the collider ring. The sandstone is a massive competent rock which stands vertical in outcrop.

PHOTO 2
Claggett Formation outcrop in railroad cut approximately four miles north of E8. Note the thinly bedded nature of the shales and sandstones and their jointing pattern.

PHOTO 3
Claggett, Judith River contact, in fault zone; southwest side of collider area, K3+4000. The thicker more resistant basal sandstones of the Judith River Formation are underlain by softer shales and sandstones of the Claggett Formation.

PHOTO 4
Judith River Formation, west side of collider area, approximately 2 miles NE of K4. This formation forms prominent ridges and hills in the area, due to its many more resistant sandstone beds.

PHOTO 5 & PHOTO 6
The Bearpaw Shale exposed in a cut slope at Broadview, Montana. The shale is fine-grained and thinly bedded.

PHOTO 7
Lennep Sandstone Formation. Outcrop along Montana State Highway Route No. 3 approximately 3 miles south of F8. The sandstone strikes parallel to the highway and dips 26 degrees down from right to left.

PHOTO 8
Hell Creek/Tullock outcrop, east side of collider area, F9. Note the differential weathering of the sandstone in comparison to the softer underlying shales.

PHOTO 9
Hell Creek/Tullock outcrops, northeast side of collider area approximately one mile due west of J4. Note the gentle topography due to the weathering of these soft sediments.

PHOTO 10
Judith River Formation, southwest side of collider area, 2 miles NE of K4. The sandstone is thinly bedded and contains crossbedding. The fractures are a result of previous faulting.

PHOTO 11
Judith River Formation, southwest area of collider, at E4. Note the relatively massive sandstone being broken and cut by numerous fractures. This area is within the Lake Basin fault zone.

PHOTO 12
Fault in Judith River Formation, southwest area of collider, 2.5 miles NW of E3. Note near-horizontal sandstone beds on the right side of the photo and upturned beds in the fault zone. The left side of the fault is downthrown.

3.3 GEOHYDROLOGY

3.3 GEOHYDROLOGY

The Comanche Basin is underlain by at least 12 individual aquifers through approximately 8000 feet of geologic strata. These water-bearing zones include alluvium, sandstone, and carbonate aquifers. Generally, only the upper four aquifers will yield water of sufficient quantity and quality to be used for domestic purposes or stock water. These same uppermost units will be encountered in the proposed SSC tunnel.

Permeability and transmissibility of the formations in the SSC site are low, and aquifers are limited only to certain of the more pervious horizons within the formation. Groundwater volumes are typically adequate for domestic use and livestock supplies and not adequate for irrigation. Groundwater supplies adequate to serve this project could only come from the Madison formation, some 7-8,000 feet below grade, for this reason Billings city water is the recommended water source.

The focus of this section will be on the upper aquifers: Quaternary Alluvium, Lennep (Fox Hills) - Hell Creek formations, Judith River sandstone, and the Eagle sandstone. Other nonproductive and deeper water-bearing strata will be discussed briefly.

3.3.1 Detailed Geohydrologic Characteristics

Detailed evaluations are given for each aquifer within the study area which would be intercepted by the tunnel. The overall hydrologic regime, recharge area, piezometric surface elevation, general water quality and interaction with surface waters will be discussed for each of the uppermost aquifers. Also, primary and secondary permeability of the aquifers and seasonal variations in groundwater levels will be addressed. The static water levels are shown on Figure 3.3-1.

3.3.1.1 Quaternary Alluvium Aquifer

The proposed tunnel location will not intersect saturated alluvium. The maximum thickness of alluvium near the proposed SSC is estimated at 75 feet near the center of the ring 6 to 8 miles from the tunnel.

The alluvium in Comanche Basin is directly connected to surface water. Because this basin is internally drained, runoff from surrounding hills flows into the central area and saturates unconsolidated sediments. Groundwater levels in alluvium fluctuate significantly and range from at or above ground surface in wet seasons to several feet below ground surface after several dry years.

3.3.1.2 Lennep (Fox Hills) – Lower Hell Creek Aquifer

In the site area, the Lennep – Lower Hell Creek formation will be intersected by the tunnel in the northeast perimeter over a length of approximately 16 miles, where it may exceed 400 feet in thickness (Feltis, 1982). Water-bearing sandstone beds may constitute less than one-third of this thickness.

Sandstone units of the upper Cretaceous Lennep (Fox Hills) formation and the lower part of the Hell Creek formation are aquifers in eastern Montana. However, in the site area, this formation has considerably less hydraulic conductivity than in eastern Montana, and water wells in the lower Hell Creek sandstone yield small supplies of potable groundwater. The deeper Lennep sandstone usually provides a relatively good source of water (Hall and Howard, 1923). Domestic water well logs indicate yields ranging up to 30 gpm from 6-inch diameter wells completed in these units. Aquifer tests were completed approximately 9 miles northeast of the proposed site (Montana Bureau of Mines and Geology, 1980). Results are summarized below:

Unit	Transmissivity (feet/day)	Hydraulic Conductivity (gal/square foot/day)
Hell Creek	1.0	0.33
Lennep	3.6	0.46

These quantities are probably provided by primary porosity. During this investigation, in-place permeability tests were conducted at two depths in this formation (see log of test boring DH-8, Appendix 3A) which indicate that in these zones the sandstone is argillaceous and nearly impermeable.

Aquifer recharge probably occurs at outcrops adjacent to the proposed site. Where these units surface along the flanks of numerous anticlines, domes, and other geologic features in central Montana, precipitation and other surface water infiltrates. Minimal recharge may also occur along faults and fractures. Groundwater level fluctuations of 20 feet are not uncommon (Custer, 1976).

3.3.1.3 Judith River Formation Aquifer

The SSC tunnel will intercept the Judith River formation in the north perimeter and the south perimeter for a total distance of approximately 14 miles.

The maximum thickness of the Judith River Formation in the Comanche Basin is about 400 feet, approximately 175 to 200 feet of which may be low volume sandstone aquifers (Feltis, 1982).The Judith River formation is a locally significant aquifer in central Montana, particularly east and northeast of this site, with sandstones producing water of variable quality due to lithologic variations. However, as noted below, conductivity is negligible. No aquifer test reports are available for the Judith River formation in the area of Comanche Basin. Two separate USGS reports for the area indicate that the Judith River formation yields adequate supplies for domestic use (Ellis and Meinzer, 1924, Hall and Howard, 1923). Water-bearing zones within the Judith River formation are usually weakly cemented, medium to coarse, grained sandstone. However, cores taken at the proposed SSC site were moderately to well cemented with significant silica and argillaceous material between sand grains. This formation to the east commonly has a hydraulic conductivity of 0.01 to 10 gal/square foot/day (Freeze and Cherry, 1979). However, at this site packer tests (see Drill Holes [DH-1 and DH-10] in the Appendix 3A) showed the hydraulic conductivity of two zones was negligible, while one zone had a value of 4 gal/square foot/day.

Recharge of Judith River sandstone aquifers occurs where it is exposed to precipitation and surface water. Typically, this occurs along the flanks of numerous domes and anticlines in central Montana. Because these exposures are usually topographically high, the Judith River aquifers are commonly artesian. Depending on distance to recharge, groundwater level fluctuation of up to 20 feet in wells is common between seasons.

3.3.1.4 Eagle Sandstone Aquifer

The Eagle formation is an aquifer in north-central and western south-central Montana. Generally, the Eagle becomes fine-grained east of 108 West Longitude and is not considered a viable aquifer in eastern Montana (Noble, Bergantino, Patter, Sholes, and Schofield, 1982).

At the proposed site, the Eagle formation will be intercepted by the tunnel for approximately five miles along the western perimeter. In the Comanche Basin, the Eagle formation is up to 400 feet thick with 200 to 225 feet of sandstone and the remainder interbedded sandstone, siltstone and claystone (Feltis, 1982). Generally the better aquifer zones within the Eagle are in the upper part and the lower part. The largest reported yield in a domestic well in the area is 15 gpm.

The Town of Broadview obtains its water from the lower part of the Eagle formation with an 8-inch diameter well providing up to 80 gpm (Montana Dept of Health and Environmental Sciences, 1985). Hydraulic conductivity of Eagle sandstone has not been determined by aquifer tests in the Comanche Basin. However, based on grain size distribution, the Eagle probably has a range similar to that of the Judith River formation, 0.01 to 10 gal/square foot/day (11). Packer tests (see DH-3 in Appendix) at the site indicated hydraulic conductivities of 3.2 to 3.8 gal/square foot/day.

Recharge of Eagle sandstone aquifers is the same as for Judith River and Lennep - Hell Creek aquifers: where sandstone units are exposed to surface water. Generally, this recharge occurs along the numerous structural uplifts of central Montana, thus providing artesian conditions within the aquifer with distance from the recharge area. Groundwater level fluctuations in Eagle sandstone aquifers are similar to other aquifers except that the tunnel intercept occurs in the western perimeter where the Eagle is close to recharge; therefore, fluctuations may only amount to a maximum of 10 feet seasonally.

3.3.1.5 Sub-Tunnel Aquifers

Approximately ten other water-bearing formations occur in the 6,000 feet of strata below the Eagle sandstone. None of these units would be intersected by the proposed SSC tunnel. In order of occurrence below the Eagle, these water-bearing strata include the Telegraph Creek formation, the Dakota Sandstone, the Lakota sandstone, the Swift Formation, the Tensleep Formation, the Madison limestone, the Jefferson formation, Cambrian limestones and the Precambrian crystalline rocks. Although some of these formations locally have extremely high hydraulic conductivities due to secondary porosity, depth and poor water quality probably preclude usage in the Comanche Basin.

3.3.2 Groundwater Quality and Local Aquifer Resources

Potential groundwater resources in the vicinity of the site are limited to the four upper aquifers: alluvium, Fox Hills - lower Hell Creek formations, Judith River formation, and Eagle sandstone. Deeper water bearing zones exist but are not used due to poor water quality and excessive drilling depths. Most of the groundwater underlying the proposed SSC is characterized as sodium bicarbonate type with occasional high concentrations of other ions. Total dissolved solids (TDS) varies significantly in near-surface aquifers.

Generally, Judith River formation aquifers have the lowest TDS concentration (400 ppm) and alluvial aquifers have the highest TDS concentration (16,000 ppm). Groundwater quality samples were collected from four wells in the proposed SSC area to confirm historic water quality data. Analytical results are included in the Appendix 3A.

3.3.2.1 Typical Water Quality Results

A range of water quality is present in each aquifer. Analyses of water from the upper four aquifers are presented below with concentrations in parts per million (Hall and Howard, 1923).

	CONSTITUENTS					
Aquifer	TDS	SiO2	Fe	Ca	Mg	Na + K
Alluvial						
Maximum	16283	31	2.0	452	214	1617
Minimum	382	9	Trace	21	1.0	38
Fox Hills - Hell Creek						
Maximum	2675	20	1.7	80	86	925
Minimum	208	4	0.03	.08	3.8	8.5
Judith River						
Maximum	8134	21	5.2	235	159	2438
Minimum	638	5.5	.05	3	1	70
Eagle Sandstone						
Maximum	1549	23	2.2	196	127	307
Minimum	469	13	.24	39	24	70

	HCO_3	SO_4	CL	NO_3	Total Hardness
Alluvial					
Maximum	761	3984	315	6.9	1905
Minimum	229	106	4.0	Trace	57
Fox Hills - Hell Creek					
Maximum	1063	1349	103	3.8	553
Minimum	156	31	2	Trace	14
Judith River					
Maximum	1726	2322	636	5.1	1240
Minimum	340	5.2	5	Trace	16
Eagle Sandstone					
Maximum	593	670	27	4.8	1010
Minimum	271	87	8	.29	196

3.3.2.2 Effect of Proposed SSC on Groundwater

Although local groundwater resources will not likely be used for project needs, other impacts are possible. During tunnel construction, a few (less than 10) downgradient wells that are dependent on thin or susceptible aquifers and that are relatively close to the ring may be affected. This will be a temporary condition until the liner is placed. The groundwater regime will then return to normal. Due to the competence of the strata, subsidence due to dewatering will not occur.

To summarize, groundwater conditions underlying the site are limited to four near-surface low volume aquifers, which include alluvium, Lennep - Hell Creek formation, Judith River formation, and Eagle sandstone. The Judith River formation provides most of the useable domestic groundwater in the Comanche Basin. Groundwater chemistry includes relatively high concentrations of TDS and sporadically high concentrations of sulfate and chloride. Generally, groundwater in this area is a sodium bicarbonate-type water, although ionic concentrations can vary widely depending on the depth of the well intake and by lateral changes in the aquifer.

The quantity of groundwater is limited to the water bearing zones within the formations, and is controlled by primary porosity. Hydraulic conductivities of these water bearing zones are low with typical values in the range of 0.1 to less than 10 gallons/square foot/day.

Groundwater at the depth of tunnel construction will be limited to the more permeable zones and very low volumes, in the range of 1 to 8 gpm for every 100 lineal feet of 12-foot diameter tunnel.

3.3.3 Water-Related Underground Construction Conditions

Within the ring, water-related underground construction conditions will be variable depending upon the formation, depth, faulting, and fracturing. The water conditions are not considered significant, but can be dealt with in the normal course of construction. These conditions are summarized below:

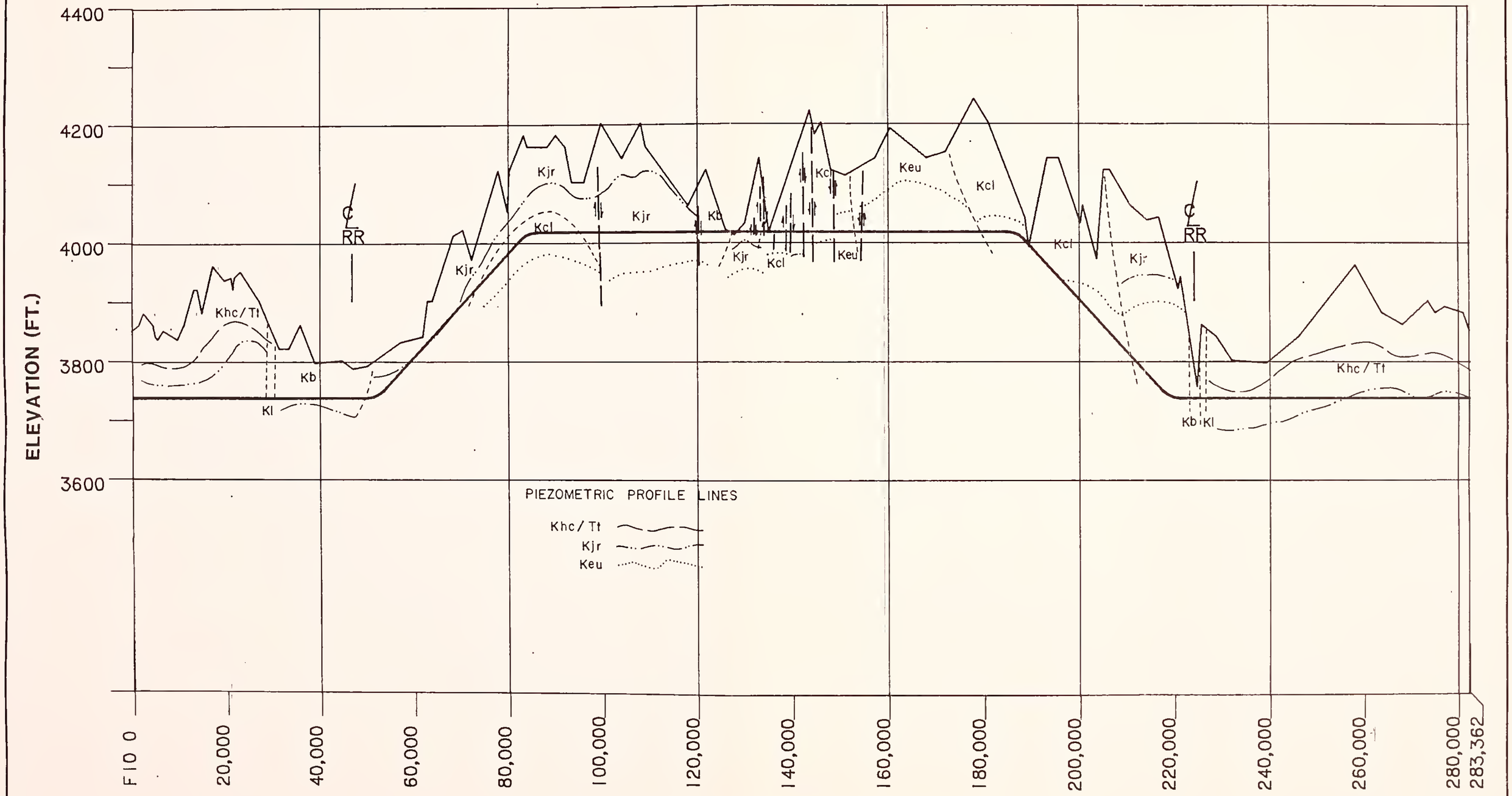
- Eagle Sandstone and Judith River Sandstone. These two formations will be encountered for about 18 miles of the tunnel as described in Section 3.2.2. While water flow is expected within the tunnel bore as it penetrates some zones of these formations, it will be less than 8 gpm/100 feet of tunnel which can be readily controlled within the tunnel bore. Most of the groundwater is expected to be fair quality, except near claystone contacts.

- Lennep (Fox Hills) and Hell Creek Formations. These two formations will be excavated for about 16 miles of the tunnel, and are expected to produce minor groundwater flow from the sandstone units as they are excavated in the tunnel. Flow is expected to be low (one gpm/100 feet of tunnel) and readily controllable within the tunnel bore. Groundwater is expected to have moderate sulfate content.

- Claggett and Bearpaw Formations. The tunnel will intersect these two formations for about 15 miles. Only slight seepage from some of the sandier and/or carbonaceous lenses is expected.

- Fault Zones. Within and adjacent to the faults along four miles of the southwest arc, fracturing of the rock units will result in increased groundwater flows. These flows are expected to be on the order of five gpm/100 feet of tunnel.

- Alluvial Water. Alluvial groundwater will not affect the tunnel.



MONTANA – AUGUST 1987

FIGURE 3.3-1
SSC TUNNEL PROFILE

3.4 SEISMICITY AND FAULTING

3.4 SEISMICITY AND FAULTING

While there are a number of faults within and near the site, the last apparent movement is associated with Rocky Mountain building events in late Pliocene time (Alpha and Fanshawe, 1954). The site, and surrounding vicinity, during historic time is an area of relatively slight and rare seismic activity.

3.4.1 Characterization of Site Seismicity

The proposed site is in a region characterized as having low seismicity within recent geological time. Figure 3.4-2 shows the proposed site on the Uniform Building Code seismic map of the United States (UBC, 1982). The site is in Seismic Zone 1, which is the lowest category of seismic activity.

Seismic activity in the geologic past is evidenced in the Lake Basin Fault Zone, which crosses one side of the collider ring; however, no historical earthquakes are associated with the Lake Basin Fault Zone. The zone has been described as being associated with local mountain building events, and having moved most recently during late Pliocene time (Johns, 1982), about 1.6 million years ago. Surface evidence along the zone reveals that near its southeastern boundary it is covered by Pleistocene terrace gravels which have not been displaced (Bergantino, 1980; Rogers and Lee, 1923), decisively placing latest movement older than 10,000 years. During this investigation, geologists found undisplaced Flaxville gravel terrace deposits atop the eroded fault trace, in the area near Huntley, Montana. These Pliocene gravels clearly indicate that no movement has occurred for at least 1.6 million years. It is therefore considered an inactive fault zone. Refer to Section 3.4.3 for a detailed description of the fault zone.

Individual fault lengths are about 6 miles or less. An equation correlating maximum earthquake intensity and surface rupture length indicates an event of 6.3 or less would have produced these faults (Okamoto, 1973).

From 1869 to the present, only a small number of earthquakes have been recorded by instruments or reported by individuals within 100 miles of the site. None of the reported events were strong enough to assign a magnitude; the recorded events ranged in magnitude from 2.8 to 4.0. Figure 3.4-1 presents the inferred epicenter locations, dates and magnitudes of all of the reported and recorded events within a 100-mile radius of the site.

3.4.2 Estimate of Maximum Ground Acceleration Probability

The site is located in UBC Seismic Risk Zone 1. USGS open file Report 82-1033 indicates a probability of 90 percent that horizontal acceleration will not exceed 0.04g within a 50 year period. See Figure 3.4-2 for referenced information.

3.4.3 Local Faults

The faults in the southwest part of the site are all part of an en echelon system known as the Lake Basin Fault Zone. The zone is about 115 miles in length and 6-1/2 miles in width, trending about N.80°.W. from Hardin on the east to the Crazy Mountains on the west. (Alpha and Fanshawe, 1954; Thom, 1923)

Individual faults within the zone are primarily steep and normal, their average strike is about N45°E., and their length about 1 to 5 miles.

Various authors have postulated the latest movement along the zone to be associated with local mountain building events to the west and suggest that the latest movement was Pliocene. During this investigation, mappable evidence has been found to support the conclusion that the latest movement of the zone was in late Pliocene time, about 1.6 million years ago. The area between Huntley and Corinth, northeast of Billings, Montana, has several high level terraces, dated by fossils to be of Oligocene age. Lower terraces consist of Flaxville gravels, Miocene to Pliocene in age, and early to middle Pleistocene terraces are found at the lowest levels of this area.

This area was carefully examined and one fault, approximately 3 miles south of Huntley, Montana, was traced to where it intersected an upper level terrace, dated as late Pliocene in age. The terrace deposit and the upper bedrock contact was not displaced, and no surface expression of the fault remains on the top of the level terrace deposit. A smaller fault, approximately 1 mile south of Corinth (between Huntley and Hardin, Montana), was found to be overlain by early to middle Pleistocene terrace gravels. The contact between the upper bedrock units and the gravel is very distinct, with no offset of the contact. Terrace gravels dated as middle to late Pleistocene in age were mapped near Hardin. During this investigation, geologists carefully examined several of the areas in which the faulted Cretaceous and/or Tertiary formations are faulted and the zone subsequently covered with Pleistocene terrace deposits.

The terrace deposits, as well as the upper weathered bedrock contact surface, were found to be undisplaced at every location examined. The photos on the enclosed plate are typical of the area examined. The above mappable field evidence clearly indicates that no movement of this zone has occurred since early Pliocene time and clearly extends the latest movement of this zone beyond 1.6 million years.

3.4.4 Liquefaction Potential

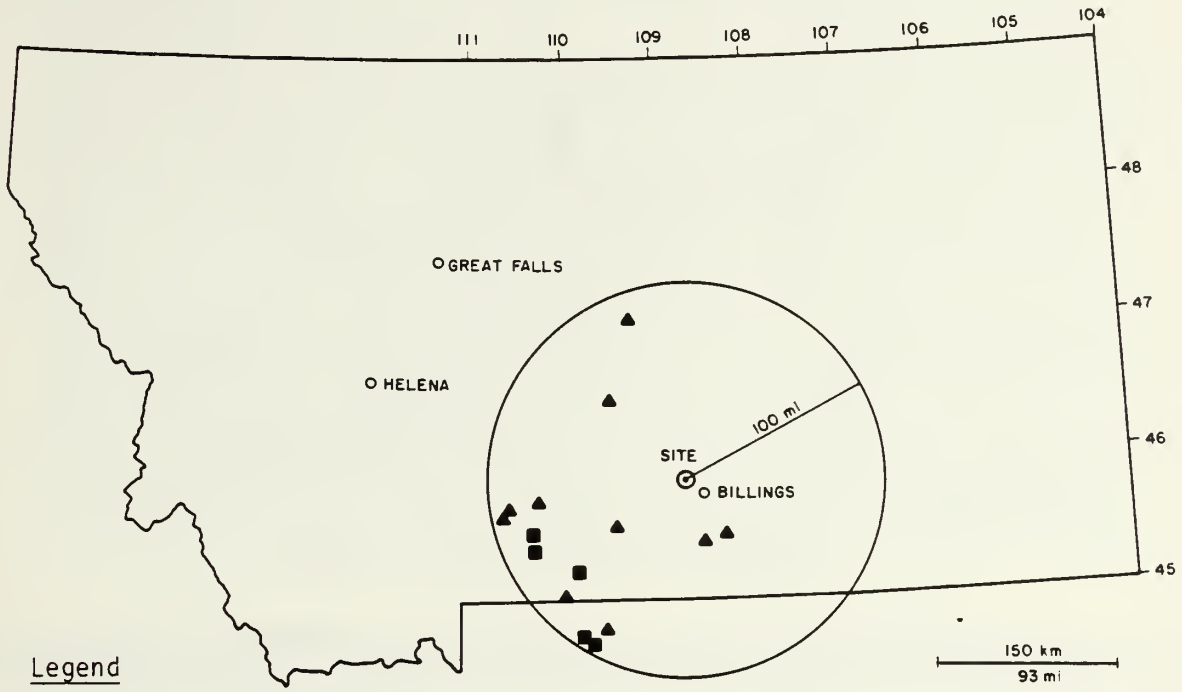
Liquefaction of soils can occur if four basic conditions exist simultaneously:

- The soil consists of a sand or silt having a grain size distribution within specific limits
- The soil exists in a loose condition
- The soil is saturated
- Strong earth shaking occurs

Evaluation of the soils, water levels and seismicity of this site consistently lead to the conclusion that liquefaction will not occur.

Visual mapping and exploration borings show that soil is generally thin; usually less than ten feet. The soils are predominantly clays and clayey sands which are not within the grain size distribution limits of liquefiable soils. Penetration test "N" values in the soils are normally in the range indicating medium dense for sands and stiff to very stiff for silts or clays. Studies by Seed and Idriss (1971) indicate soils having "N" values within those ranges are not susceptible to liquefaction. None of the exploration borings encountered saturated soils. From field observations it is expected that some localized perched water levels could exist resulting in saturation of some soil layers, but this is not a general condition of the site. Finally, the seismicity of this site is low; it is discussed in Section 3.4.1. From the USGS seismicity map there is a 90 percent probability that a maximum horizontal ground acceleration of 0.04g will not be exceeded within 50 years. Ground accelerations greater than 0.13g are usually required to induce liquefaction (Seed and Idriss, 1971).

A0787024



Recorded Epicenters:

DATE D /M /Yr	LAT	LONG	MAG
25/01 1965	45.50	110.30	4.0
06/08 1965	44.70	109.80	3.9
20/01 1967	44.74	109.77	3.6
28/03 1967	45.16	109.91	3.6
14/04 1978	45.30	110.26	2.8

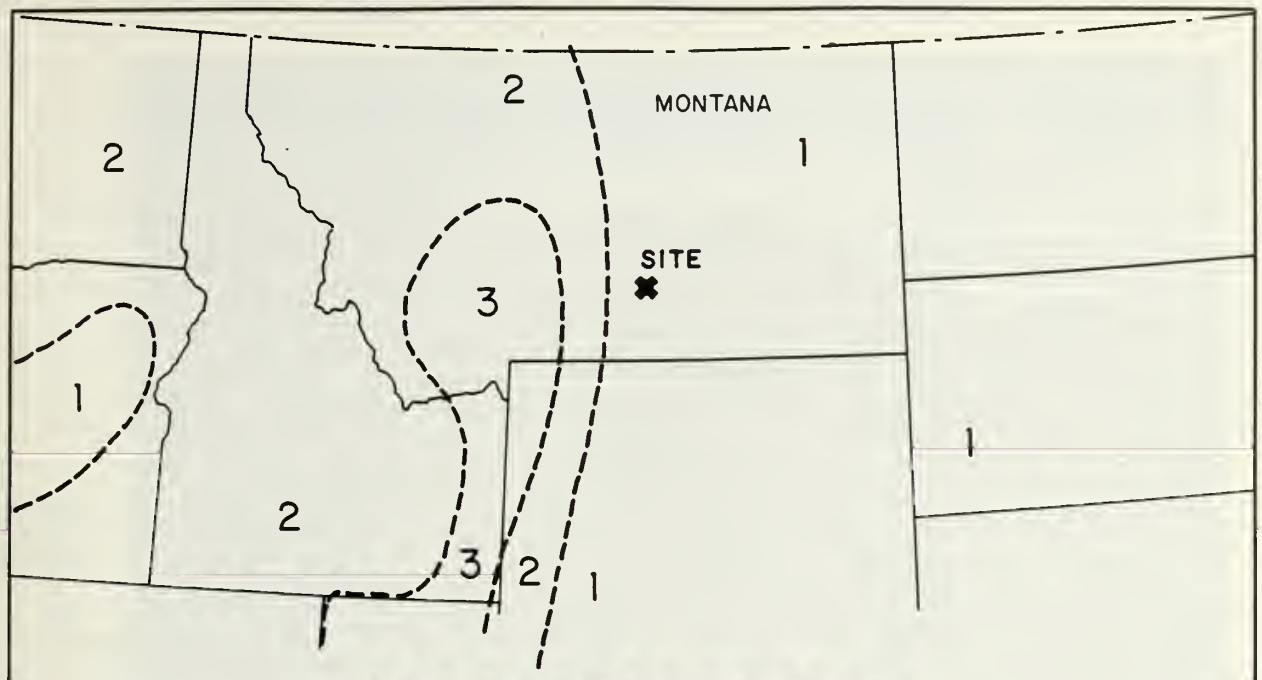
Reported Epicenters:

DATE D /M /Yr.	LAT	LONG	MAG
01/03 1928	45.47	108.29	0.0
17/07 1930	45.60	110.60	0.0
31/07 1930	45.66	110.55	0.0
31/10 1935	46.47	109.50	0.0
13/02 1936	47.07	109.30	0.0
14/02 1936	47.07	109.30	0.0
20/02 1945	45.52	109.43	0.0
29/04 1952	45.73	110.23	0.0
02/05 1952	45.73	110.23	0.0
24/08 1959	45.42	108.53	0.0
21/03 1963	44.90	109.90	0.0
03/04 1963	45.10	109.80	0.0
10/04 1950	44.78	109.55	0.0
25/04 1952	45.02	109.95	0.0

Source: Montana Earthquakes 1869-1979, Historical Seismicity and Earthquake Hazard, Qamor and Stickney, Montana Bureau of Mines and Geology 1983.

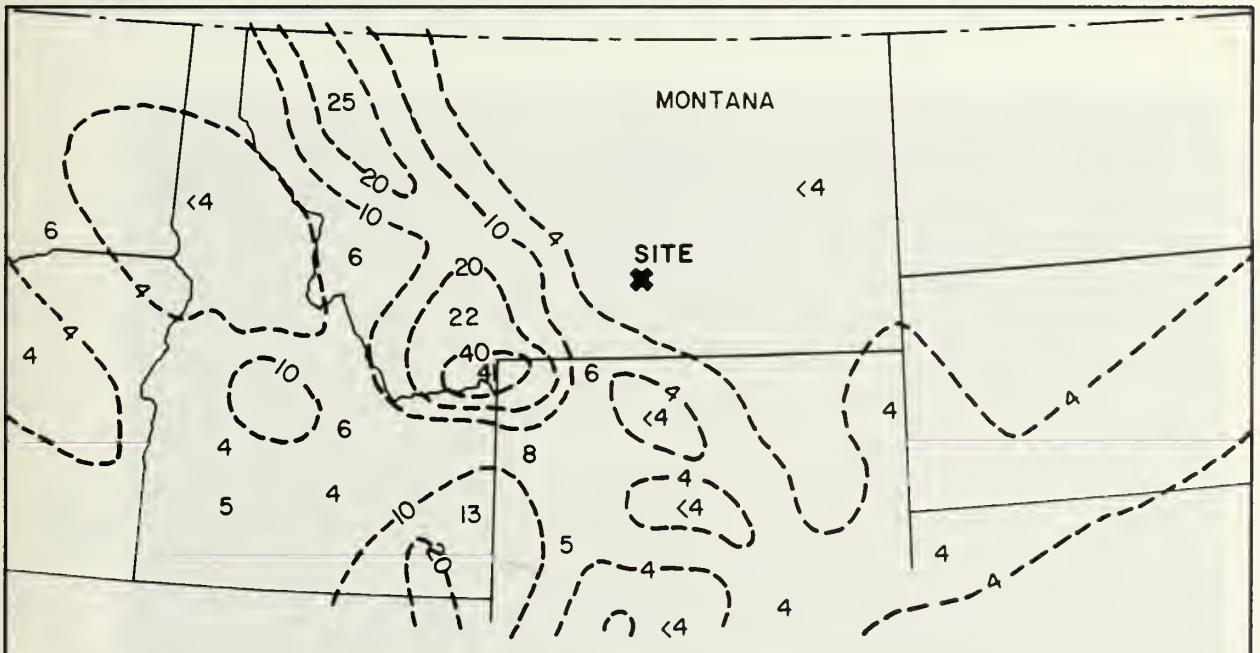
Figure 3.4-1
LOCATIONS OF RECORDED AND REPORTED EPICENTERS

A0787026



Seismic Zone Map of the United States

Source: Uniform Building Code, 1982 Edition



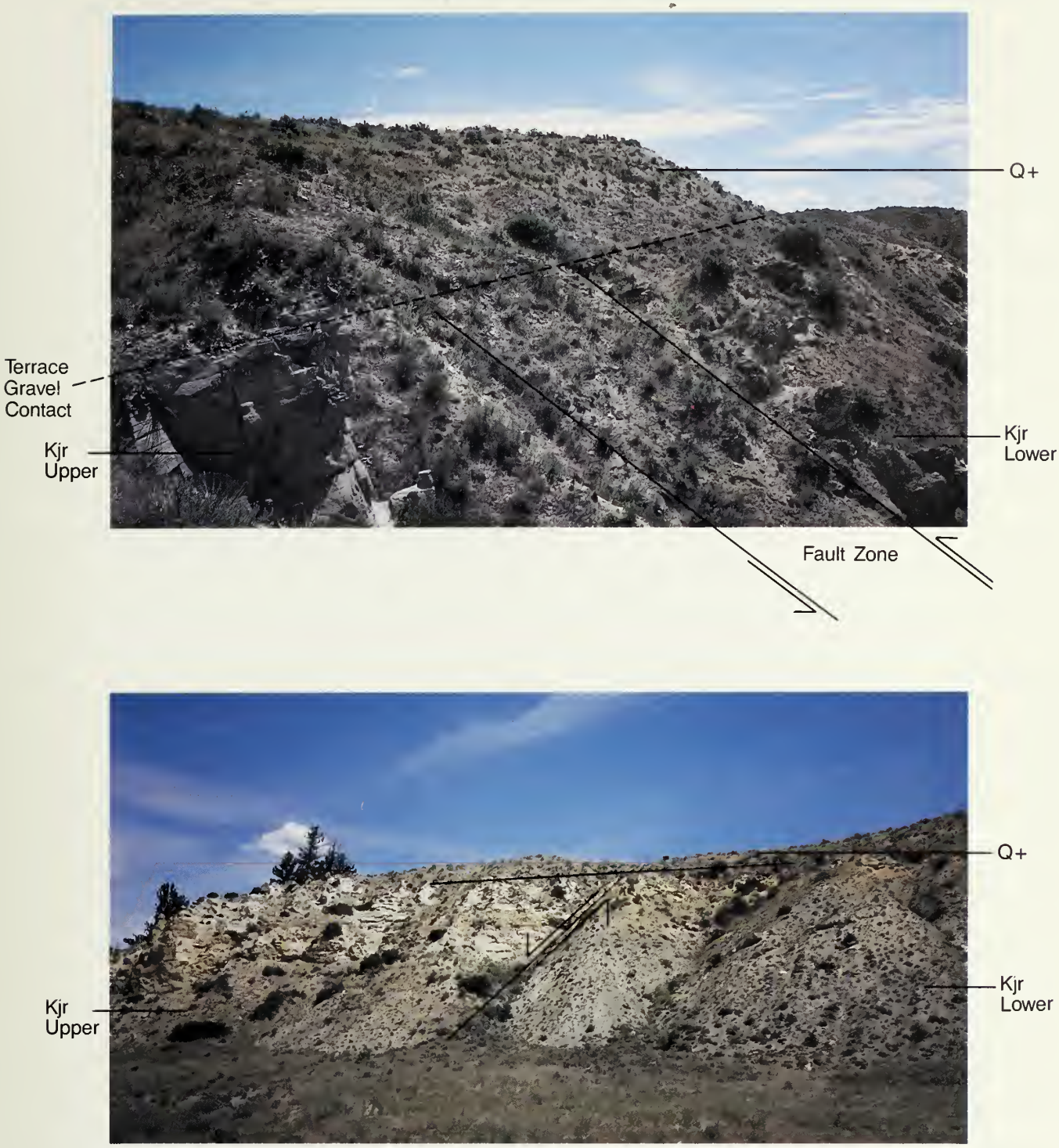
Preliminary Map of Horizontal Acceleration
(Expressed as Percent of Gravity) in Rock with
90% Probability of not being Exceeded in 50 Years

Source: Probabilistic Estimators of Maximum Acceleration and Velocity in Rock in the Contiguous United States. USGS Open File Report 82-1033, Plate No 2, 1982.

Figure 3.4-2
SEISMIC ZONE MAPS

Figure 3.4-3 RELATIVE AGE AND DEPOSITION LAKE BASIN FAULT ZONE

Sections 22 & 23, T1N, R33E, near Hardin, Montana



Note Kjr Upper and Kjr Lower — Upper and Lower Units of the Cretaceous Judith River Formation Qt — Pleistocene Terrace Deposits.

3.5 TUNNELING AND UNDERGROUND CONSTRUCTION

3.5 TUNNELING AND UNDERGROUND CONSTRUCTION

As discussed in the previous section, most of the SSC construction will involve sandstone, siltstone, and claystone rock units, with only minor, thin, local alluvium. These units are competent and dip moderately to gently eastward, except for the area within the fault zones, where fracturing is more severe and dips are greater. Groundwater is expected to be present within some of the more permeable zones of the thicker sandstone units, but flow will be small and controllable within the tunnel.

In the following section, the physical and engineering properties of the rock, as they relate to tunnel and open excavation construction, will be discussed. Tunneling and construction methods appropriate to the project, and a section-by-section description of the ring construction is also presented, as well as the use/disposal of the excavated material.

3.5.1 Relevant Soil and Rock Units and Appropriate Construction Methods

The proposed tunnel of the SSC ring lies within six geologic formations as illustrated in Figure 3.2-2. The geologic formations are the Hell Creek/Tullock, Lennep, Bearpaw, Judith River, Claggett, and Eagle formations, described in Section 3.2.3.

Approximately 70 percent of the collider ring lies within formations that are predominantly sandstone, including Eagle, Judith River, Hell Creek, and Lennep. The remaining 30 percent is located in formations that are predominantly claystone and/or siltstone. Two of the formations, the Eagle and Judith River, contain sandstone units which are limited aquifers in the site area. One of the claystone units, the Bearpaw, is bentonitic, in the lower portions. The tunnel is driven into the bentonite units for about 4 percent of its length.

Two construction methods are proposed for this site. A cut-and-cover technique is recommended for areas of relatively shallow depth to the collider ring and the large service, experimental, and booster areas. Tunnel boring is recommended for areas where cover is generally deeper than 50 feet, or due to surface and economic considerations. The rock units around the collider ring are characteristic of soft rock; therefore, soft rock tunneling methods are appropriate for ring construction.

To describe the rock units and their relation to the construction methods for the collider ring, it is convenient to divide the ring into segments and discuss each segment individually. These segments are adopted based on geotechnical properties and the excavation methods. Figure 3.1-4 in the map folder illustrates the segments that are discussed in the following:

- Segment J6 to K2 - Construction will begin within the booster and main campus area early in the schedule. Relatively large volumes of material will be generated from the surface, access, booster and experimental facilities as well as the tunnel, which will be constructed by boring machine in this segment. See Figures 3.5.1 to 3.5.4.

  The construction will take place in the Hell Creek/Tullock formation, and involve primarily sandstone. Typical logs of this material are shown on DH-4 and DH-8 in the Appendix. Groundwater flow on the order of one to two gpm/100 feet of tunnel will be encountered in the deeper sandstone units. This can be readily controlled by pumping within the tunnel and vertical excavations. Due to the thin-bedded nature of the sandstone units, and the low bedding dip angle, some roof bolting will be required, followed by shotcrete support. Support is discussed in more detail in Section 3.5.2.1.

  The excavated material will be predominantly sandstone, suitable for construction of engineered fills for structures and roadways within the campus complex and booster area as well as the access road from Highway 3 to the campus.

- Segment K2 to F1 (11,000 to 28,000) - This segment will encounter Hell Creek/Tullock and Lennep formations, which will be primarily sandstone. Through most of this section the sandstone units have low dip angles, and some zones are relatively thin-bedded, requiring a support system consisting of random rock bolts and shotcrete to prevent roof spalling. Groundwater inflow on the order of one to two gpm/100 feet of tunnel is expected. The last 1500 feet of this section will encounter massive, cross-bedded sandstone with compressive strengths on the order of 2000 to 3000 psi. This reach will not require support.

  All of the excavated sandstone will be suitable for engineered fills within the campus area and the access road from Highway 3 to the campus, which is adjacent to this section.

- Segment F1 + F2 (28,000 to 48,400) - This segment is in the Bearpaw formation, primarily a soft, massive claystone. The unconfined compressive strength of the material is about 200 psi; and the RQD varies from 15 in the upper, partially decomposed zones to 80 in the fresh claystone. At tunnel depth, the moisture content is low (about 9-10%) and the RQD average about 70-75. The logs for Test Borings DH-6 and DH-9 in the Appendix are typical of this material. In this segment, the water inflow is slight, but the claystone is sensitive to change in moisture content and air slaking. Support systems need to be constructed immediately. A full shield tunnel boring machine equipped with a rib expansion track assembly and associated trailing gear is proposed. Sulfate resistant concrete will be necessary in this section.

  Excavated material will decompose to Fat CLAY (CH), which will have to be placed in non-structural embankment areas, and/or used to backfill the cut-cover section described in the following paragraph. The ring has been located so that no major structures are supported on potentially expansive clays.

- Segment E2 to E3 (48,400 to 67,000) - This segment which is predominantly Judith River sandstone, can be excavated in the initial stage of construction by cut and cover techniques. Excavation from this segment can be used for construction and improvement of the access roads to facilitate construction of other parts of the collider ring. The RQD of the material is estimated to be about 90 to 95 percent with an unconfined compressive strength of about 3000 to 4500 psi. A 1:1 (horizontal to vertical) excavation slope is appropriate. The excavation depth varies from 15 feet to about 65 feet. This segment, when completed, can be backfilled with compacted claystone of the Bearpaw formation from the preceding tunneled section between E1+11400 and E2+5000 so that the excavated sandstone can be used elsewhere in the construction. The log for DH-10 is typical for this material.

- Segment F2 to F3 (67,000 to 93,000) - It is in the Claggett formation and consists of interbedded claystone, siltstone, and sandstone, with a preponderance of claystone and siltstone. The unconfined compressive strength of the material at the tunnel elevation is estimated to be 2000 to 5000 psi. This segment will be constructed using a tunnel boring machine. Systematic temporary roof support will be necessary for a portion of this segment due to flat bedding and thin unit thickness. The groundwater inflow will be very small and can be controlled within the tunnel. Excavated material is suitable for embankments for roadways and parking lots.

- Segment F3 to F4 (93,000 to 119,000) - This segment consists mostly of massive Judith River sandstone. Some fracturing is expected near the beginning and end of the segment, adjacent to the two fault zones. The compressive strength of the sandstone is estimated to be about 3000 to 5000 psi. The tunnel will be advanced with a boring machine, with occasional rock bolts for support. Near the fault zone, additional bolting and shotcrete will be needed. Groundwater inflow will be on the order of one to six gpm/100 feet of tunnel and can be controlled within the tunnel. The excavated material will be sandstone, suitable for engineered embankments at the service and experimental areas, access roads and embankments for the west experimental complex.

- Segment F4 to E5 (119,000 to 126,000) - This segment will be bored through claystone of the Bearpaw formation, under similar conditions to those described in Segment E1 (F1 to F2). There will be little or no groundwater flow. Excavated material will decompose to be Fat CLAY (CH), unsuitable for structural fill, but suitable beneath landscape or other non-structural areas.

- Segment E5 to K4 (126,000 to 138,000) - Within this segment the tunnel reaches the ground surface in two small valleys, and intersects six fault zones, including one at each end of the section. Repetitive sections of Bearpaw, Judith River, and Claggett formations will be encountered. Due to the shallow cover and the various large experimental and service units, this segment will be constructed using cut-and cover techniques. Cut slopes of 1:1 to 2:1 (horizontal to vertical) will be appropriate, depending upon materials and excavation depths which varies from 0 to 120 feet. Some water inflow is expected which can be handled by pumping within the excavation. Drill hole 5 is in one of the low areas near a fault in this segment.

  Excavated materials will be used to complete the tunnel cover, and for other structural embankments within the westerly experiment complex.

- Segment K4 to K6 (138,000 to 154,000) - Within this segment, the tunnel will be advanced with boring equipment through sandstone and interbedded sandstone and claystone of the Judith River, Claggett, and Eagle formations. These formations will be moderately fractured, especially near the four fault zones. Rock bolts and shotcrete will be required for roof support. Groundwater flow will be light but controllable within the bore of the tunnel. Support is further described in Section 3.5.2.1.

Excavated material will be sandstone, siltstone, and claystone, with the mixture suitable for engineered embankments within the westerly experiment complex and the service areas.

- Segment K6 to F6 (154,000 to 178,000) - Within this segment, the tunnel will be constructed in the lower units of the Eagle sandstone. Drill Hole 3, the log of which is contained in the Appendix, shows the rock is fairly massive, with compressive strength on the order of 3000 to 4000 psi. The tunnel will be advanced with boring equipment, with little or no support. Groundwater flow is expected to be on the order of two to eight gpm/100 feet of tunnel and controllable within the tunnel bore.

  The excavated material will be excellent for structural fills within the complex and access roads.

- Segment F6 to E7 (178,000 to 188,000) - The tunnel will be bored through interbedded sandstone and siltstone and claystone of the Claggett formation. Water flow is expected to be slight. Systematic rock bolting and shotcrete will be required for roof support in some of the thin bedded, flatly dipping sandstone units. This segment will be similar to Segment F2 to F3.

- Area E7 (188,000 to 191,000) - The tunnel traverses a valley and cover varies from 0 to 50 feet. Cut and Cover methods will be employed, which will both accommodate the topography and provide a surface access to the construction in the northwest arc area. Temporary cut slopes of 1:1 (horizontal to vertical) are appropriate for this cut in the Claggett formation. Test Boring DH-2 is drilled in this area and its log is shown in the Appendix.

- Segment E7 to E8 (191,000 to 209,000) - The tunnel will be bored through the Claggett formation and will be similar to Segment F6 to E7.

- Segment E8 to F8 (209,000 to 223,000) - Within this segment, the tunnel will be bored through Judith River sandstone, requiring only occasional rock bolts for support.

  Groundwater flow is expected, to be on the order of one to six gpm per 100 feet of tunnel and controllable within the bore. The sandstone material excavated from the tunnel is suitable for engineered embankments within the project.

- Area F8 (223,000 to 225,000) - The tunnel segment will be bored through the Bearpaw claystone, except for the center 500 feet, which will be cut-and-cover. The material will be similar to Segment F1-F2. Drill Hole 1 illustrates a typical contact between the Bearpaw and Judith River formations, and DH-9 is typical of the Bearpaw formation.

- Segment F8 to F10 (225,000 to 283,000) - Within the final segment, the tunnel will be advanced by boring through a massive sandstone unit for about 1000 feet (Lennep Formation), then thin-bedded sandstone units with some claystone interbeds. (Hell Creek/Tullock Formation). Unconfined compressive strength is estimated to be about 2000 to 3000 psi. Dip of the beds at the beginning of the segment is about 20 to 25 degrees easterly. Only occasional bolting for support is expected, but as the tunnel proceeds southerly, the dip flattens to about 6 degrees, and the need for roof support will increase to using grouted rock bolts and shotcrete. The booster ring, experimental halls and campus area will be constructed with open cut excavations in these materials. Slight groundwater flow is expected; controllable within the tunnel.

  The excavated material will be suitable for engineered embankments for access roads and within the east campus area.

3.5.2 Physical and Mechanical Rock and Soil Properties Related to Tunneling and Open Excavation

Physical and engineering properties specific to each of the six geologic formations encountered in the tunnel bore are shown on the Logs of Drill Holes DH-1 through DH-7 contained in Appendix 3A. In order, these test borings were drilled in:

Hole	Formation
DH-1	Bearpaw/Judith River
DH-2	Claggett
DH-3	Eagle
DH-4 and DH-8	Hell Creek/Tullock
DH-5	Alluvium/Fault Zone/Claggett
DH-6 and DH-9	Bearpaw
DH-7	Alluvium
DH-10	Judith River

Table 3.5-1 summarizes the properties of the rock units within these formations, as well as a general range of properties for upper Cretaceous and Tertiary sandstones, siltstones, and claystones within 50 miles of the site.

Table 3.5-2 summarizes test results and geologic observations of the various rock units at the site identifying their rock quality classification in accordance with D.U. Deere's methodology. Based upon this information, the bedrock units generally fall in the range of fair to excellent rock, with poor rock in the fault zones.

3.5.2.1 Tunneling Considerations

Tunneling conditions can be summarized as follows:

- Eagle, Judith River, and Lennep Formations. These sandstones are characterized as good to excellent rock. Roof supports will only be required locally, and will consist of grouted rock bolts. This will include about 40 percent of the tunnel.

- Hell Creek/Tullock Formation. These interbedded sandstone and claystone units classify as fair to good rock. Roof supports consisting of rock bolts, in the thin-bedded and/or flatly-dipping zones, will be required. Shotcrete will be required in the claystone units to prevent air slaking. This will account for about 25 percent of the tunnel.

- Claggett and Bearpaw Formations. These interbedded claystone and sandstone units of the Claggett and Massive Claystone of the Bearpaw classify as fair rock. Roof supports, consisting of grouted rock bolts, spaced about 6 feet on center and about 10 feet in length, as well as about 3 to 4 inches of shotcrete, will be required for support. This will include about 30 percent of the tunnel.

- The fractured zones within about 100 feet of the faults classify as poor rock. Within these zones systematic roof supports consisting of grouted rock bolts spaced about 3 to 4 feet on center and about 10 feet in length, as well as 4 to 6 inches of shotcrete, will be required for support. These formations include about 5 percent of the tunnel.

3.5.2.2 Vertical Borings

Rock conditions throughout most of the ring location are very good for winze, raise, and shaft boring equipment and techniques. Minimal supports will be required. The exceptions are the very fractured areas near the fault zones, which will require supports, and the Bearpaw Formation which will require supports including immediate shotcrete cover to prevent air-slaking.

3.5.2.3 Cut-and-Cover and Other Excavation

For most of the ring area, bedding orientation is favorable and temporary and permanent slopes will be controlled by the mass properties of the rock. The exception is within the closely spaced fault zone along the southwest side, where fracturing will have an effect on cut slope orientation.

All of the rock and soil materials in the construction area are rippable and open excavations can be made with conventional crawler-tractor/scraper and/or front-end loader/truck methods.

The excavated sandstone and mixtures of sandstone, siltstone and claystone can be readily compacted into engineered embankments, suitable for support of parking lots, streets, access roads and other light to moderately loaded areas. The sandstone is suitable for construction of structural embankments.

The moist density (w) of all of the excavated bedrock units, when compacted to 95 percent of the maximum density as determined by ASTM D698 will be equal to or greater than the 1.8 g/cc (112 pcf) required for the 30 feet of material immediately adjacent to the tunnel bore.

Table 3.5-3 summarizes the excavation, embankment, and other design characteristics of the various rock units which will be excavated. Figures 3.5-1 through 3.5-4 are a conceptual drawings of the service areas around the ring. In Table 3.5-4 we show hardness test results were made at the University of Illinois on rock core samples taken from borings from each of the formations to be encountered on site.

3.5.3 Unique Construction Considerations

The proposed SSC site has, from a geological/geotechnical viewpoint, some obvious advantages. There are also some disadvantages that must be considered in design and construction of the collider. These advantages and disadvantages are summarized below.

3.5.3.1 Geotechnical Advantages

- The proposed collider ring and associated facilities will be constructed almost entirely within rock, resulting in maximum stability, bearing capacity, and durability.

- The rock units, sandstone, siltstone and claystone, are generally characterized as "soft rock" which is relatively easy to excavate with tunnel boring equipment, is generally rippable in open excavation, yet is a stable material, especially in temporary construction excavations. These rock units are very economically excavated and tunnel excavation should advance rapidly.

- About 70 percent of the tunnel is in sandstone which classifies as good to excellent rock for tunneling.

Table 3.5-1

Regional and Site Rock Properties

Formation	Rock Type	Depth (ft.)	Moist Unit Weight (pcf)	Moisture Content (%)	Qu (psi)
Hell Creek/Tullock (Khc/Tt)	Sandstone	22.5 - 23.1	142	10	2150
Hell Creek/Tullock (Khc/Tt)	Claystone	60.0 - 60.4	150	9	190
Hell Creek/Tullock (Khc/Tt)	Sandstone	67.8 - 68.3	149	5	4030
Bearpaw (Kb)	Claystone	25.6 - 25.9	136	17	180
Bearpaw (Kb)	Claystone	54.0 - 54.3	148	12	640
Bearpaw (Kb)	Claystone	55.7 - 56.0	152	10	800
Judith River (Kjr)	Sandstone	91.0 - 91.4	149	6	3180
Judith River (Kjr)	Sandstone	148.5 - 148.8	156	5	5870
Judith River (Kjr)	Sandstone	152.7 - 153.0	155	5	5880
Claggett (Kcl)	Claystone	27.5 - 27.8	155	3	7120
Claggett (Kcl)	Claystone	43.9 - 44.3	157	6	1910
Claggett (Kcl)	Claystone	58.7 - 59.0	154	7	4060
Eagle (Keu)	Sandstone	53.0 - 53.4	141	10	3880

Regional Rock Properties (Middle & Upper Cretaceous within 50 miles of Site)

Formation	Rock Type	Weight (pcf)	Moist Unit Content (%)	Moisture Qu (psi)
Cody (Kc)	Claystone	145 - 154	3 - 13	1110 - 2080
Cody (Kc)	Reworked Claystone	123 - 129	20	11
Eagle (Keu)	Sandstone			6530 - 9380
Telegraph Creek (Ktc)	Claystone	149 - 155	5 - 6	170
Telegraph Creek (Ktc)	Sandstone	155	6	900
Bearpaw (Kb)	Claystone	122 - 123	15 - 28	
Judith River (Kjr)	Sandstone	158	6	980
Judith River (Kjr	Reworked Claystone	117 - 126	18 - 23	3 - 6

Table 3.5-2

Site Rock Properties And Qualities (RQD Method)

Formation Name	Rock Type	Uniaxial Compression Strength, psi	RQD	Joint Spacing, ft.	Joint Condition	Rock Quality*
Hell Creek/ Tullock	Interbedded Claystone Sandstone	190 to 4030	31 - 92	*0.2 to 1.0	Slightly rough surfaces; hard joint wall rock	Fair to Good Rock
Bearpaw Shale	Claystone	180 to 800	15 to 83	*0.2 to 1.0	Soft joint wall rock	Poor to Good Rock
Judith River	Sandstone	5880	85 to 95	10	Slightly rough surfaces; hard joint wall rock, 0.04" separation	Excellent Rock
Claggett	Interbedded Claystone and Sandstone	4060	69 to 96	*0.2 to 1.0	No separation; hard joint wall rock	Fair Rock
Eagle	Sandstone	3880	88 to 100	10	No separation; not continuous; hard joint wall rock	Excellent Rock
Fault Zone	Sandstone and Claystone	1910	25 to 50	0.2 to 1.0	Slickensided sur-surfaces; gouge 0.2" thick	Poor Rock

*Denotes bedding plane separation according to RQD method, D.U. Deere et al.

Table 3.5-3

CONSTRUCTION CHARACTERISTICS - LOCAL BEDROCK UNITS

Formation	Rock Type	Rippability	Cut Slopes* Temp	Perm	Allowable** Bearing, ksf	M/D D698 Optimum Moisture,% / Maximum Dry Density, pcf***	Embankment Slopes
Hell Creek/Tullock (Khc/Tt)	Interbedded Sandstone/Claystone	Good	1:1	2:1	10 - 15	10 - 15 / 110 - 120	2 1/2:1
Lennep (Kl)	Sandstone	Fair	1/2:1	1:1	15 - 30	10 - 15 / 115 - 120	2:1
Bearpaw (Kb)	Claystone	Fair to Good	1:1	3:1	5 - 10	15 - 20 / 105 - 115	3:1
Judith River (Kjr)	Sandstone	Fair	1:1	1 1/2:1	10 - 20	10 - 15 / 115 - 120	2:1
Claggett (Kcl)	Claystone, Sandy Shale, Thin Sandstone	Good	1:1	2:1	5 - 10	10 - 15 / 110 - 120	3:1
Eagle (Keu)	Thin to Massive Sandstone	Fair to Difficult	1/2:1	1:1	15 - 30	10 - 15 / 115 - 125	2:1

*Cut slopes are for relatively fresh bedrock and do not include consideration of local slope-controlling fractures and/or faults.

**Plus one kip per square foot/for each 5 feet of footing depth below a depth of 4 feet.

***Moisture-density is based upon moderately slaked to partially decomposed bedrock.

Table 3.5-4

SUMMARY OF ROCK HARDNESS TESTS
UNIVERSITY OF ILLINOIS

Drill Hole	Depth	Formation	Rock Type	Hammer Rebound Values, H_R	Abrasive Hardness, H_A	Total Hardness, H_T
DH-1	87.0-88.0	Judith River	SANDSTONE	27.0	0.32	15.3
DH-1	152.7-153.5	Judith River	CLAYSTONE	32.3	0.43	21.2
DH-2	20.5-21.4	Claggett	SANDSTONE	28.1	-.30	15.3
DH-2	55.2-56.0	Claggett	CLAYSTONE	27.1	-.33	15.5
DH-3	52.1-52.9	Eagle	SANDSTONE	22.7	0.21	10.4
DH-3	204.0-204.7	Eagle	SANDSTONE	26.9	0.25	13.5
DH-4	26.6-27.0	Hell Creek/Tullock	SANDSTONE	42.7	1.436	51.2
DH-4	59.2-59.9	Hell Creek/Tullock	CLAYSTONE	25.7	0.195	11.3
DH-6	34.7-35.3	Bearpaw	CLAYSTONE	20.3	0.244	10.0
DH-6	52.7-53.4	Bearpaw	CLAYSTONE	23.0	0.284	12.3

- Groundwater flows within the tunnel and excavations will be small and readily controllable.

- Eighty to 90 percent of the excavated materials will be suitable for engineered and/or structural embankments.

- The site topography is relatively flat, yet rolls enough to provide for surface access (cut-and-cover) at various critical locations around the ring, giving natural access for tunneling and thereby expediting construction.

- The tunnel bore will intersect all fault zones nearly perpendicular, minimizing the effect on stability.

- The site is seismically inactive.

3.5.3.2 **Geotechnical Disadvantages**

- About 10 percent of the ring is in Bearpaw claystone, and about 25 percent of the claystone within this Formation is bentonitic. This will require some consideration in tunnel design and construction, but can be accounted for in normal construction practices.

3.5.4 Recommended Construction Techniques

Two different methods of construction are proposed for the tunnel at this site. A cut and cover technique is recommended for areas where depth is generally less than 50 feet, and for large experimental service and booster areas. Underground tunnel boring is recommended for areas where cut and cover was considered uneconomical or impractical.

The surface excavating equipment proposed is typical of equipment utilized in the surface mining and construction industry, including crawler tractors and scrapers or front-end loaders and trucks. The tunnel boring equipment is typical of shield tunneling equipment being used in similar soft-rock underground applications.

The cut and cover technique is proposed for about 20 percent of the total length of the collider ring. The cut slopes are estimated to vary from 1:1 to 2:1 (horizontal to vertical) depending on the material encountered. Front-end loaders and trucks and/or scrapers are appropriate to excavate the cut and cover areas. Scrapers, bulldozers, and compactors will replace backfill and compact the trench after the precast or cast-in-place concrete line is constructed. Open cut excavation is proposed for the collision and access halls. A slope of 1:1 is estimated to be suitable for these excavations. These experimental halls will be built at a depth approximately 30 feet below the centerline of the main collider ring (i.e. at a depth of about 125 feet below the ground surface) and must support loads

up to 9 tons/square foot. At this depth, the overburden pressure being excavated is approximately equal to 125 feet of rock or about 9 tons/square foot. Therefore, the rock at that depth, with an unconfined compression strength of about 2000 to 5000 psi, will readily support the required load without shear failure or and it will be possible to balance load and settlement to accommodate the anticipated structural conditions.

Tunneling is proposed for about 80 percent of the main collider ring. The rock encountered in the ring area is characterized as soft rock. A wheel excavator tunnel boring machine with a diameter of about 12 feet will be used to excavate the rock. The cutterhead, contained within a shield, is equipped with soft rock cutting teeth. The muck which is removed from the face falls to the bottom of the shield where it will be moved to the back of the tunnel boring machines by means of horizontal mucking arms and conveyors, buckets, belt drives, or similar equipment. Support, as required, will be placed behind the boring operation.

A permanent liner will be required in the final design for all of the tunnel length and will consist of precast concrete segments or slip formed concrete. The permanent liner should follow closely behind the excavation for most parts of the tunnel particularly in the Bearpaw formation. A railroad tunnel driven in the Claggett formation (25 percent of collider ring goes through this formation) about four miles Northwest of the site was examined. The following is a summary of our observations and findings. Photographs are included in Appendix 3A.

- Name and Location: Painted Robe Tunnel in Golden Valley County, Montana.

- Dimensions: Approximately 1000 feet long; Horseshoe shape; 12 feet wide by 18 feet high.

- Type of Liner: Cast-in-place unreinforced concrete. This tunnel has been in service since 1920. Inspection of the tunnel revealed that there is no apparent structural distress to the tunnel due to approximately 70 feet of overburden rock. Minor concrete spalling was observed in the roof at the concrete joints due to the deteriorating effect of sulfate in groundwater.

Ten rock cores were selected, typical of all of the various rock units encountered by the SSC tunnel, and tested for Schmidt rebound hardness, Hr, and abrasion hardness, Ha. From these data, total hardness, Ht, was determined to be in the range of 11 to 50. A copy of these test results is shown on Table 3.5-4.

Using correlation data from Tarkoy's thesis , updated by Dr. Alfred Hendron of the University of Illinois, a correlation was made between total hardness and instantaneous tunneling rate for single full-face, wheel type tunnel boring machine (TBM). An instantaneous advance rate of 20-30 feet per hour is expected.

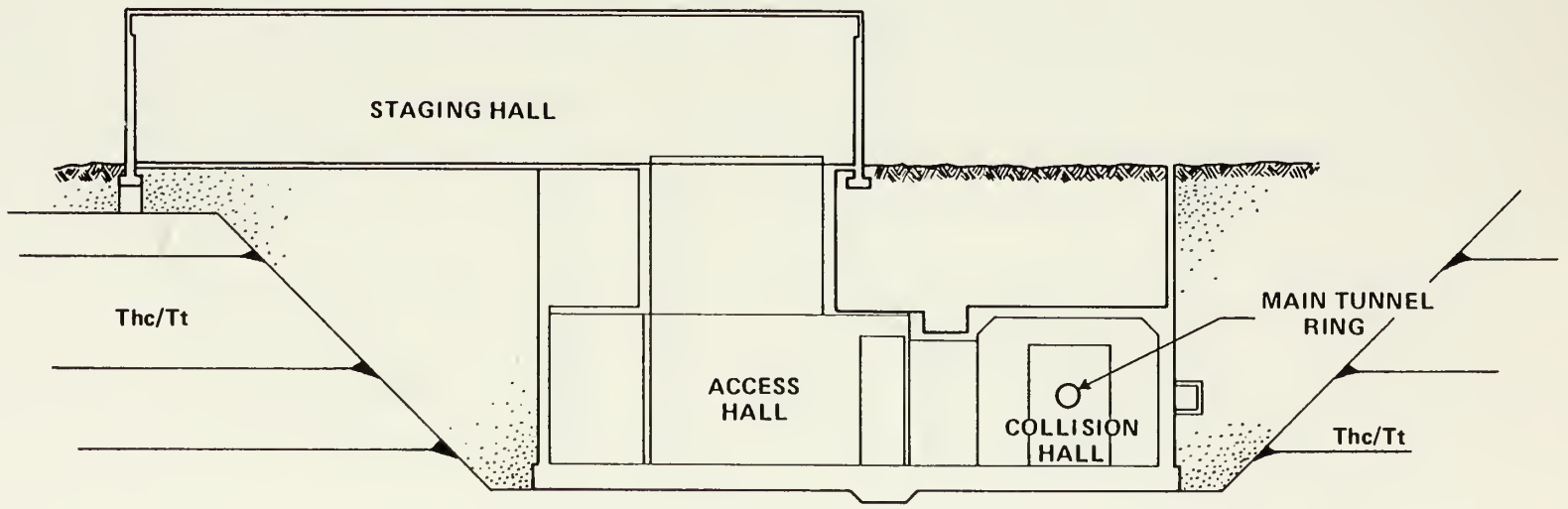
Considering that the TBM was utilized 33 percent of the time, a three-shift daily advance rate is conservatively estimated to range from 160 to 240 feet per day for a single TBM. Because of the magnitude of this project, multiple tunnel boring machines will be utilized. In the cut and cover sections, production rates of 2000-3000 cubic yards per day are common in these rock types.

3.5.5 Spoil Sites

Whether open cut-and-cover or bored tunnel, construction of the ring and appurtenances will generate a significant quantity of material. The nature and properties of this material is discussed elsewhere in the section, but at least two-thirds of it will have properties similar to Clayey and/or Silty SAND (SC or SM). With the exception of the high-plasticity Fat CLAY (CH) soils derived from the bentonitic layers (about 4 percent of the total excavation), the material can be compacted into structural embankments suitable for all but the heaviest structural loads, and the excavated sandstone is suitable for structural fills. With suitable surfacing thickness to accommodate anticipated traffic volumes and loads, embankments for access roads, internal streets, parking lots and service areas can be constructed from these materials.

To plan for the disposal of the excavated material, the volume was estimated and an appropriate swell factor was applied to account for an increase from in-situ to embankment. The topography was examined at the east and west campuses and at the individual service areas. Most, if not all, of the excess quantities from the ring excavation will be needed to construct the campuses and service areas. However, if these features do not require all of the excavated materials, the embankments for the various access roads will certainly require all that remains. It was concluded that all of the material can be used within 5 miles of excavation or tunnel access point with the average surface haul being less than two miles. These conclusions were subsequently field verified by re-examining the site, and identifying the location and extent of required embankment construction.

A0787019

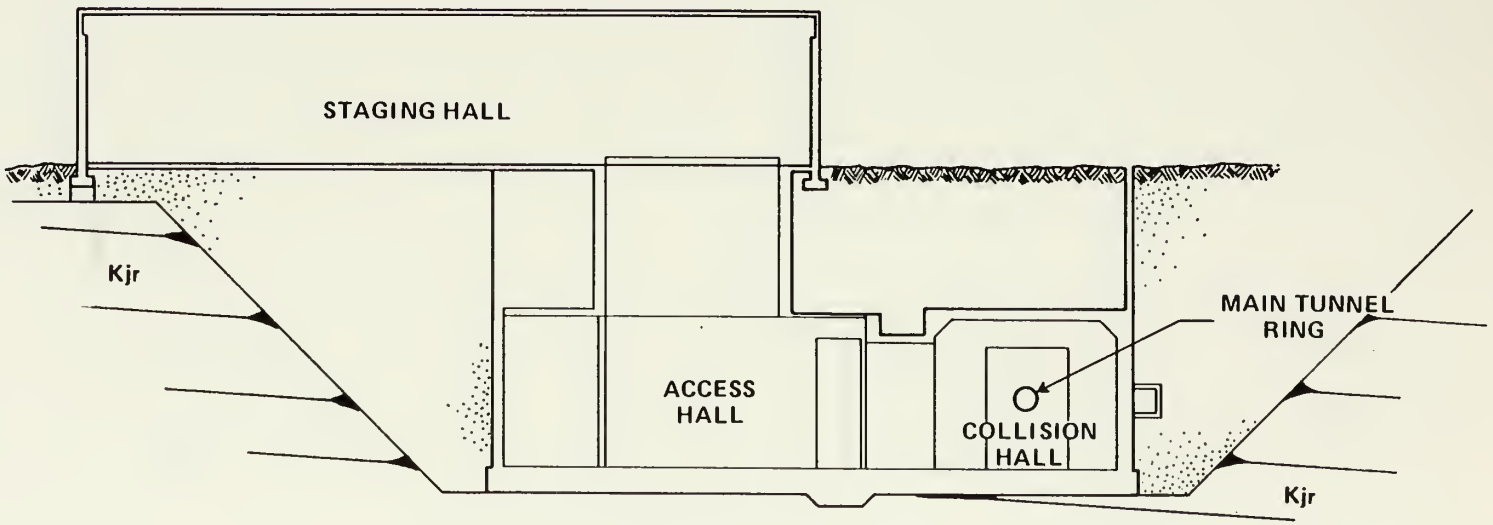


SUBSURFACE CROSS-SECTION AT COLLISION HALL K1, K2

STATE OF MONTANA 9/2/87

Figure 3.5-1
CROSS SECTION AT K1, K2

A0787016

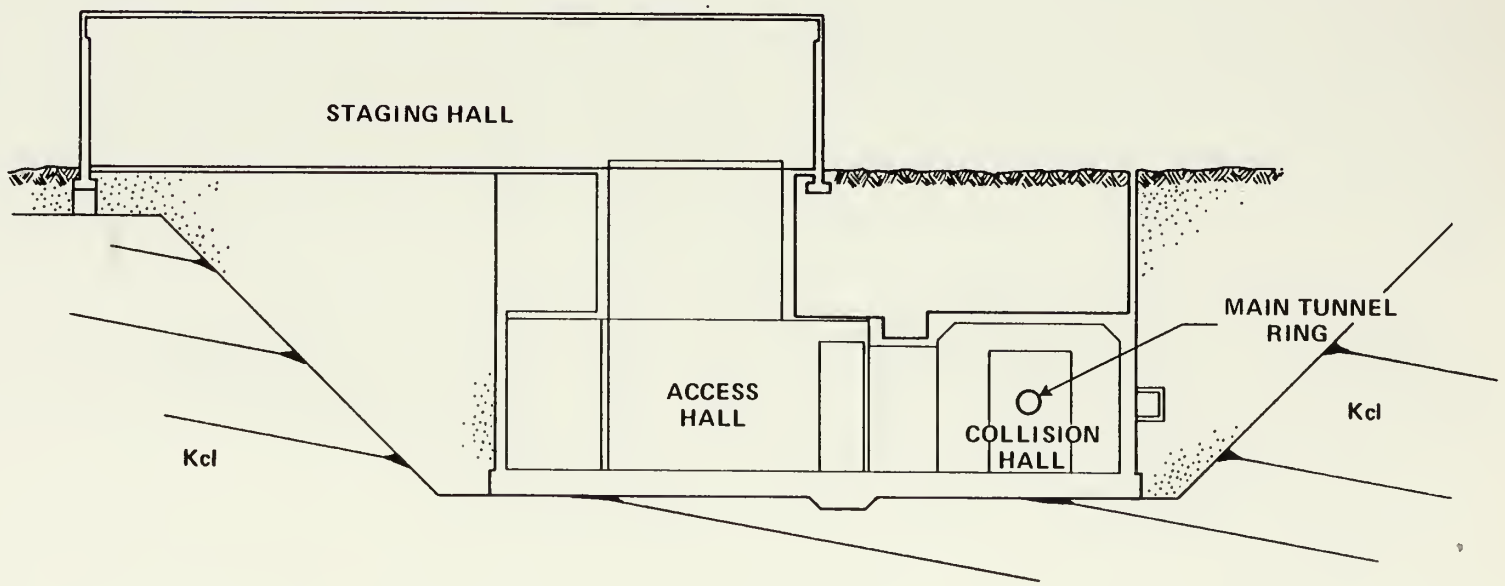


SUBSURFACE CROSS-SECTION AT COLLISION HALL K3

STATE OF MONTANA 9/2/87

Figure 3.5-2
CROSS SECTION AT K3

A0787017

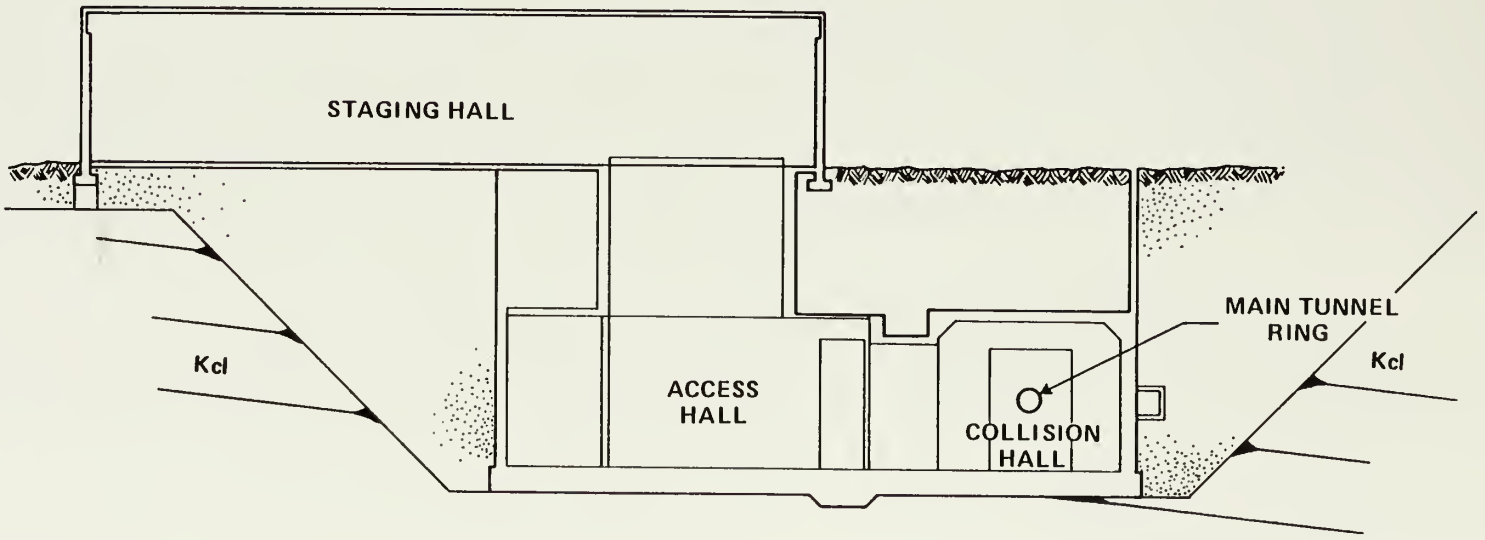


SUBSURFACE CROSS-SECTION AT COLLISION HALL K4

STATE OF MONTANA 9/2/87

Figure 3.5-3
CROSS SECTION AT K4

A0787018



SUBSURFACE CROSS-SECTION AT COLLISION HALL K6

Figure 3.5-4
CROSS SECTION AT K6

REFERENCES

REFERENCES

Alpha, Andrew G. and Fanshawe, John R., 1954, Tectonics of Northern Bighorn Basin Area and Adjacent South-Central Montana, Billings Geological Society, Fifth Annual Field Conference.

Berg, R. B., July, 1969, Bentonite in Montana, Montana Bureau of Mines & Geology, Bul. 74.

Bowen, C.F., Nov. 1918, Anticlines in a Part of the Musselshell Valley, USGS Bulletin 691-F.

Custer, S.G., 1976, Shallow groundwater salinzation in dryland-farm areas of Montana: Montana Water Resources Research Center Report No. 79, 214 p.

Ellis, A.J. and Meinzer, O.E., 1924, Groundwater in Musselshell and Golden Valley Counties, Montana: United States Geological Survey Water Supply Paper 518.

Feltis, R.D., 1982, Map showing altitude of the Swift Formation, Montana: United States Geological Survey Water Resources Investigation 82-4029, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982, Map showing cumulative thickness of sandstone in the Eagle Sandstone and Telegraph Creek Formation, Montana: United States Geological Survey Water Resources Investigations 82-4032, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982, Map showing total thickness of the Eagle Sandstone and Telegraph Creek Formation, Montana: United States Geological Survey Water Resources Investigation 82-4033, 1 sheet 1:1,000,000.

Feltis, R.D., 1982, Map showing cumulative thickness of sandstone in the Judith River Formation, Montana: United States Geological Survey Water Resources Investigations 82-4038, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982, Map showing total thickness of the Fox Hills - Lower Hell Creek aquifer, Montana: United States Geological Survey Water resources Investigations 82-4041, 1 sheet, 1:1,000,000.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater, Prentice - Hall, Inc., Englewood Cliffs, New Jersey, 604 p.

Hall, G.M., and Howard, C.S., 1923, Groundwater in Yellowstone and Treasure Counties, Montana, USGS Water Supply Paper 599, 118 p.

Hancock, E.T., July 1918, Lake Basin Field, Montana, USGS Bulletin 691-D.

Johns, Willis M. et al., 1982, Neotectonic Features of Southern Montana East of 112C30' West Longitude, Montana Bureau of Mines and Geology, Open File Report No. 91.

Knechtel, Maxwell M. and Patterson, Sam H.J., 1956, Bentonite Deposits in Marine Cretaceous Formations, Hardin District, Montana and Wyoming; United States Geological Survey Bulletin 1023, 116 p.

Lawlor, R.E., 1956, Cretaceous Stratigraphy of Central Montana, Billings Geological Society Seventh Annual Field Conference.

Montana Bureau of Mines and Geology, 1980, Summary of Fox Hills, Hell Creek and Tullock well drilling and aquifer test results: Unpublished departmental report, Billings, MT, 21 p.

Montana Department of Health and Environmental Sciences, 1985, Report on operation and maintenance of water supply systems -- wells: Town of Broadview: Unpublished departmental report, Helena, MT 3 p.

Noble, R.A., Bergantino, R.N., Patton, T.W., Sholes, B., Daniel, F., and Schofield, J., 1982, Occurrence and characteristics of groundwater in Montana: Montana Bureau of Mines and Geology, MBMG, v.1, Great Plains Region, 82 p.

Northern Engineering and Testing, 1957-1987, Various Geotechnical Engineering Studies and Reports.

Oamar, Anthony I., and Stickney, Michael C., 1983, Montana Earthquakes, 1969-1979, Historical sensitivity and earthquake hazard: Montana Bureau of Mines and Geology Memoir 51, 79 p.

Okamoto, S., 1973, Introduction to Earthquake Engineering, Wiley, N.Y., 571 p.

Reeves, Frank, Feb, 1927, Geology of the Cat Creek and Devils Basin Oil Fields and Adjacent AReas in Montana, USGS Bulletin 786-B.

Roberts, Albert E., 1972, Cretaceous and Early Tertiary Depositional and Tectonic History of the Livingston Area, Southwestern Montana, USGS Professional Paper 526-C.

Sales, John K., Oct., 1968, Crustal Mechanics of Cordilleran foreland deformation: a regional and scale-model approach: American Association of Petroleum Geologists Bulletin, v. 52, no. 10, p. 2016-2044.

Seed and Idriss, September 1971, Soil Mechanics and Foundation Division, Proceedings of the American Society of Civil Engineers.

Smith, John G., September 1965, Fundamental Transcurrent Faulting in Northern Rocky Mountains AAPG Bulletin, v. 52, no. 10, p. 2016-2044.

Sonnenberg, Frank P., 1956, Tectonic patterns of central Montana, Billings Geological Society Seventh Annual field Conference.

Stickney, Michael C. and Bartholomew, Mervin J., In Press, Seismicity and late Quarternary faulting of the northern Basin and Range Province, Montana and Idaho: submitted for August, 1987 publication in the Bulletin of the Seismological Society of America, 32 p.

Thom, W.T., Jr., 1923, The relation of deep-seated faults to the surface structural features of central Montana: American Association of Petroleum Geologists, v. 7, no. 1, p. 1-13.

Uniform Building Code, 1982 Ed., Seismic Zone Map of the United States.

Bergantino, R.N. 1980 Geologic Map of the Hardin 1° x 2° Quadrangle 6, Southeastern Montana, Montana Bureau of Mine and Geology.

Rogers, G.S. and Lee, W., 1923, Geology of the Tullock Creek Coal Field, USGS Bulletin 49.

Thom, W.T. et al., 1935, Geology of Big Horn County and the Crow Indian Reservation, Montana, USGS Bulletin 856.

APPENDIX 3A

APPENDIX 3A

- Logs of Test Borings (DH-1 to 10)
- Natural Moisture Profile of the Bearpaw Shale (with DH-9)
- Summary of Well Water Quality Tests
- Bibliography

Exploration Boring Log

Geomechanical Legend

Degree of Weathering:

Symbol	Description
F	Fresh: Sound, Hard Rock
SW	Slightly Weathered: Weathering incipient in matrix, rock remains sound and hard.
MW	Moderately Weathered: All minerals show alteration, slightly altered joint wall rock.
VW	Very Weathered: Decomposed rock, but retains original rock characteristics, soft joint wall rock.

Jointing: Frequency of jointing in joints per foot.

Discontinuities:

CJ — Type of Discontinuty
~ — Joint surface roughness
OX — Type of infilling

Type		Roughness		Infilling	
OJ	Open Joint	——	Smooth	OX	Oxides
CJ	Closed Joint	~~	Slightly Wavy	Clay	
FJ	Filled Joint	~~	Rough	Pyrite	
BJ	Bedding Joint	⌒	Curved	Calcite	

Dip: Discontinuity inclination angle from horizontal.

Bieniawski, Z.T., 1976

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LOG OF EXPLORATION BORING

JOB NO. 87-544

HOLE NO. 1

SHEET 1 OF 4

DRILL TYPE: SOIL / ROCK Mobile B-50	CLIENT Stone and Webster Engineering Corporation
SIZE, TYPE OF BIT NQ Core Barrel 2-15/16" Tricone Rock Bit	PROJECT Superconducting Super Collider
CASING: SIZE NW LENGTH 25'	LOCATION SE 1/4, NW 1/4, NE 1/4 Section 8, T4N, R23E
TOTAL NO. OF OVERBURDEN SAMPLES TAKEN 0	
Disturbed 0 / Undisturbed 0	ELEVATION: TOP OF HOLE 3879* / GROUNDWATER Not Encountered
TOTAL NO. CORE BOXES 3 / TOTAL CORE RECOVERY FOR BORING (%) 89	THICKNESS OF OVERBURDEN, FT. 1.0 / DEPTH DRILLED INTO ROCK, FT. 164.0 / TOTAL DEPTH OF HOLE, FT. 165.0
REMARKS *Elevation interpolated from topographic map. **Uniaxial compressive strength (Qu), psi	STARTED 6/11/87 COMPLETED 6/13/87
	DRILLED BY C. Nelson
	LOGGED BY W. Henning

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	JOINTS/FT	DISCONTINUITIES: TYPE	DISCONTINUITIES: DIP
0									
1.0		TOPSOIL with Organic Material							
		SANDSTONE; red brown color, fine grained, moderately cemented, thinly bedded, moderately weathered, Bearpaw Formation.							
7.0									
10		CLAYSTONE; medium brown, soft rock, blocky structure, occasional bentonite seams, interbedded sandstone lenses, very fine grained sand, Bearpaw Formation.							
		Sandstone lense between 9.0 to 12.0 feet.							
20				181 psi		MW	2	CJ/OX	75°
30.6		Argillaceous SANDSTONE; gray, very fine grained, moderately cemented, breaks along bedding planes, occasional thin claystone seams, Bearpaw Formation.	74	15	25.6 - 35.6	SW	1	BJ/OX	10°
40									

NET 122D

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 1 SHEET 2 OF 4

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	GEOMECHANICAL: JOINTS/FT	GEOMECHANICAL: DISCONTINUITIES TYPE	GEOMECHANICAL: DISCONTINUITIES DIP
40									
41.0		CLAYSTONE; dark gray, soft rock, thinly bedded, moderately weathered, occasional sandstone interbeds, bentonite lenses, Bearpaw Formation.							
50		Numerous thin bentonite seams at 51.0 feet.							
60									
70									
		Sand content increasing below 76.0 feet.							
80									
82.0		SANDSTONE; white to light gray, very fine grained, well cemented, argillaceous, thinly bedded, occasional seams of carbon detritus, massive, Judith River Formation.				F	1	CJ / PYRITE	70°
			95	92	84.0 - 94.0				
0				3184 psi					

NET 122E

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 1 SHEET 3 OF 4

DEPTH, Ft.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	GEOMECHANICAL: JOINTS/FT	GEOMECHANICAL: DISCONTINUITES TYPE	GEOMECHANICAL: DISCONTINUITES DIP
95		Claystone seam between 97.0 to 98.0 feet.							
105		Sandstone interbedded with numerous shale lenses between 110.0 to 112.0 feet.							
115									
125		CLAYSTONE; gray, sandy, soft rock, thinly bedded, weathered, carbon detritus, Judith River Formation.							
135									
139.0		SANDSTONE; light gray, fine to medium grained, well cemented, massive, carbon detritus, Judith River Formation.		5875 psi					

NET 122E

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 1 SHEET 4 OF 4

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	GEOMECHANICAL: JOINTS/FT	GEOMECHANICAL: DISCONTINUITIES TYPE	GEOMECHANICAL: DISCONTINUITIES DIP
150		SANDSTONE; light gray, fine to medium grained, well cemented, massive, carbon detritus, Judith River Formation.	98	95 5881 psi	144.5 - 154.5	F	2	CJ	60°
160									
165.0		Bottom of Hole							

In-Place Permeability Test Results

Depth, Ft.	Permeability, cm/sec
86.0-94.0	less than 1×10^{-6}

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LOG OF EXPLORATION BORING

JOB NO. 87-544

HOLE NO. 2
SHEET 1 OF 2

DRILL TYPE: SOIL / ROCK	Mobile B-53
SIZE, TYPE OF BIT	NQ Core Barrel and 2-15/16" Tricone Rock Bit
CASING: SIZE NW	LENGTH 10.0'
TOTAL NO. OF OVERBURDEN SAMPLES TAKEN	0
Disturbed 0	Undisturbed 0
TOTAL NO. CORE BOXES 2	TOTAL CORE RECOVERY FOR BORING (%) 95
REMARKS	*Elevation interpolated from topographic map **Uniaxial compressive strength (Qu), psi
CLIENT	Stone and Webster Engineering Corporation
PROJECT	Superconducting Super Collider
LOCATION	Southwest Corner, Section 16 T4N, R22E
ELEVATION: TOP OF HOLE	4057*
GROUNDWATER	Not Encountered
THICKNESS OF OVERBURDEN, FT.	5.0
DEPTH DRILLED INTO ROCK, FT.	74.0
TOTAL DEPTH OF HOLE, FT.	79.0
STARTED	6/15/87
COMPLETED	6/16/87
DRILLED BY	B. Krueger
LOGGED BY	W. Henning

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	JOINTS/FT	DISCONTINUITIES: TYPE	DISCONTINUITIES: DIP
0		FILL; Lean Clay, very stiff, moist, medium plasticity, light brown.							
5.0		SANDSTONE; light gray, very fine to fine grained, poorly cemented, thinly bedded, occasional thin claystone interbeds, Claggett Formation.							
10									
20			91	56	20.0 - 30.0	SW	1	BJ / OX	3°
26.5		CLAYSTONE; light to dark gray, sandy, moderately hard rock, thinly bedded, slightly weathered, numerous sandstone interbeds 1/4" to 1/2" thick, spaced about five inches apart, Claggett Formation.							
30									
34.0		Agrillaceous SANDSTONE; gray, fine grained, moderate cementation, scattered claystone lenses, slightly weathered.							
40									

NET 122D

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 2 SHEET 2 OF 2

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	JOINTS/FT	DISCONTINUITIES: TYPE	DISCONTINUITIES: DIP
40		Argillaceous SANDSTONE; gray, fine grained, moderate cementation, scattered claystone lenses, slightly weathered.							
49.0		CLAYSTONE; gray, sandy, soft rock, massive, slightly weathered, fine grained sand, widely spaced closed joints, Claggett Formation.							
			98	84 4063 psi	55.0 - 60.0	SW	1	BJ	2°
60.0		Argillaceous SANDSTONE; dark gray, fine grained, well cemented, thinly bedded, occasional thin shale interbeds, Claggett Formation.	87	69	60.0 - 61.6	SW	1	$\frac{\sigma_3}{\sigma_x}$	85°
70.0									
79.0		Bottom of Hole							

In-Place Permeability Test Results

Depth, ft.	Permeability, cm/sec
18.0-30.0	2×10^{-3}

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LOG OF EXPLORATION BORING

JOB NO. 87-544

HOLE NO. 3

SHEET 1 OF 5

DRILL TYPE: SOIL / ROCK Mobile B-53	CLIENT Stone and Webster Engineering Corporation
SIZE, TYPE OF BIT NQ Core Barrel and 2-15/16" Tricone Rock Bit	PROJECT Superconducting Super Collider
CASING: SIZE NW LENGTH 15'	LOCATION Northwest Corner, Section 17 T3N, R22E
TOTAL NO. OF OVERBURDEN SAMPLES TAKEN 0	
Disturbed 0 / Undisturbed 0	ELEVATION: TOP OF HOLE 4208* / GROUNDWATER 4154
TOTAL NO. CORE BOXES 5 / TOTAL CORE RECOVERY FOR BORING (%) 97	THICKNESS OF OVERBURDEN, FT. 0.3 / DEPTH DRILLED INTO ROCK, FT. 211.7 / TOTAL DEPTH OF HOLE, FT. 212.0
REMARKS *Elevation interpolated from topographic map **Uniaxial compressive strength (Qu), psi	STARTED 6/10/87 / COMPLETED 6/15/87
	DRILLED BY B. Krueger
	LOGGED BY R. Dombrouski

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	JOINTS/FT	DISCONTINUITIES: TYPE	DISCONTINUITIES: DIP
0.3		TOPSOIL with Organic Material							
		SANDSTONE; tan, fine grained, well cemented, moderately bedded, hard rock, Eagle Formation.							
10		Claystone seam between 14.0 to 14.2 feet							
20									
30									
40									

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 3 SHEET 2 OF 5

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	GEOMECHANICAL: JOINTS/FT	GEOMECHANICAL: DISCONTINUITIES TYPE	GEOMECHANICAL: DISCONTINUITIES DIP
40									
49.0		Argillaceous SANDSTONE; gray, very fine grained, moderate to well cemented, widely spaced joints, breaks along bedding planes, inter-							
54.0		GWL (6/15/87) bedded zones with 1/4" to 1/2" thick claystone seams spaced 1" to 2" apart, Eagle Formation.	92	3883 psi 69	50.0 - 57.0	SW	4	BJ	5°
60			99	98	57.0 - 67.0		0		
70									
80									
90									

NET 122E

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 3 SHEET 3 OF 5

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	GEOMECHANICAL: JOINTS/FT	GEOMECHANICAL: DISCONTINUITES: TYPE	GEOMECHANICAL: DISCONTINUITES: DIP
95		Argillaceous SANDSTONE; gray, very fine grained, moderate to well cemented, widely spaced joints, breaks along bedding planes, inter-bedded zones with 1/4" to 1/2" thick claystone seams spaced 1" to 2" apart, Eagle Formation.							
105									
115									
125									
135									
145									

NET 122E

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 3 SHEET 4 OF 5

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	GEOMECHANICAL: JOINTS/FT	GEOMECHANICAL: DISCONTINUITIES TYPE	GEOMECHANICAL: DISCONTINUITIES DIP
150									
160									
170		Argillaceous SANDSTONE; gray, very fine grained, moderate to well cemented, widely spaced joints, breaks along bedding planes, interbedded zones with 1/4" to 1/2" thick claystone seams spaced 1" to 2" apart, Eagle Formation.							
180									
190		Breaks appear drilling induced.	95	88	190.0 - 197.0	F	0		
197.0									
200		SANDSTONE; gray, very fine grained, well cemented, silica cement, compositionally clean, uniform grained, massive, Eagle Formation.	100	100	197.0 - 207.0		0		

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LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 3 SHEET 5 OF 5

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	GEOMECHANICAL: JOINTS/FT	GEOMECHANICAL: DISCONTINUITIES TYPE	GEOMECHANICAL: DISCONTINUITIES DIP
200		SANDSTONE; gray, very fine grained, well cemented, silica cement, compositionally clean, uniform grained, massive, Eagle Formation.	100	100	197.0 - 207.0				
			100	100	207.0 - 212.0		0		
212.0		Bottom of Hole							

In-Place Permeability Test Results

Depth, ft.	Permeability, cm/sec
55.0-67.0	2×10^{-4}
200.0-212.0	2×10^{-5}

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LOG OF EXPLORATION BORING

JOB NO. 87-544

HOLE NO. 4

SHEET 1 OF 3

DRILL TYPE: SOIL / ROCK	Mobile B-50
SIZE, TYPE OF BIT	NQ Core Barrel and 2-15/16" Tricone Rock Bit
CASING: SIZE	NW
LENGTH	15.0'
TOTAL NO. OF OVERBURDEN SAMPLES TAKEN	0
Disturbed	0
Undisturbed	0
TOTAL NO. CORE BOXES	3
TOTAL CORE RECOVERY FOR BORING (%)	74

REMARKS
*Elevation interpolated from topographic map
**Uniaxial compressive strength (Qu), psi

CLIENT	Stone and Webster Engineering Corporation
PROJECT	Superconducting Super Collider
LOCATION	Northeast Corner, Section 34 T4N, R24E
ELEVATION: TOP OF HOLE	3851*
GROUNDWATER	3836.8 (6/10/87)
THICKNESS OF OVERBURDEN, FT.	6.0
DEPTH DRILLED INTO ROCK, FT.	134.0
TOTAL DEPTH OF HOLE, FT.	140.0
STARTED	6/08/87
COMPLETED	6/10/87
DRILLED BY	C. Nelson
LOGGED BY	W. Henning

DEPTH, FT.	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	JOINTS/FT	DISCONTINUITIES: TYPE	DISCONTINUITIES: DIP
0	Sandy Lean CLAY; stiff, moist, low plasticity, fine grained, scattered gravels, light brown (CL).							
6.0	Interbedded CLAYSTONE and SANDSTONE; gray to brown color, predominantly claystone with closely spaced 1/2" to 12" thick sandstone layers, poorly cemented, soft rock, very fine grained sandstone, Hell Creek/Tullock Formation.							
14.2	GWL (6/10/87)							
18.0								
20	Argillaceous SANDSTONE; brown, salt and pepper appearance, fine grained, weak to moderately cemented, massive, hard rock between 23.5 to 25.0 feet, Hell Creek/Tullock Formation.		2153 psi					
		78	67 (1)	20.0 - 30.0	SW	0	BJ	5°
30	(1) Breaks appear drilling induced.							
40								

NET 122D

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 4 SHEET 2 OF 3

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	GEOMECHANICAL: JOINTS/FT	GEOMECHANICAL: DISCONTINUITIES TYPE	GEOMECHANICAL: DISCONTINUITIES DIP
40									
41.5		CLAYSTONE; gray, sandy, soft rock, thinly bedded, some thin seams of carbon detritus, occasional sandstone lenses,. Hell Creek/Tullock Formation.							
50									
60		Carbonaceous seam between 61.2 to 61.3		188 psi		F	I	CJ	63°
			95	68	59.2 - 69.2			BROKE	
68.0						F	I	BJ	1°
70				4028 psi					
		Argillaceous SANDSTONE; light gray, fine grained, well cemented, massive, some carbon detritus, occasional thin claystone interbeds, Hell Creek/ Tullock Formation.							
80									
90									

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 4 SHEET 3 OF 3

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	GEOMECHANICAL: JOINTS/FT	GEOMECHANICAL: DISCONTINUITIES TYPE	GEOMECHANICAL: DISCONTINUITIES DIP
95		CLAYSTONE; gray, sandy, soft rock, carbon detritus, thinly bedded, scattered fine grained sandstone lenses spaced 3" to 8" apart, Hell Creek/Tullock Formation.							
105									
		Bedding plane fracture appears drilling induced.	48	31	110.0 - 116.6	SW	0	BJ	
115									
125									
		Carbonaceous seam between 130 to 131 feet.							
135.0		SANDSTONE; light gray, fine grained, moderately well cemented, scattered thin carbonaceous seams, massive rock, Hell Creek/Tullock Formation.							
140.0		Bottom of Hole							

NET 122E

Northern Engineering and Testing, Inc.

LOG OF EXPLORATION BORING

JOB NO. 87-544

HOLE NO. 5

SHEET 1 OF 2

DRILL TYPE: SOIL / ROCK	Mobile B-53
SIZE, TYPE OF BIT	NQ Core Barrel and 2-15/16" Tricone Rock Bit
CASING: SIZE	NW
LENGTH	25'
TOTAL NO. OF OVERBURDEN SAMPLES TAKEN	3
Disturbed	3
Undisturbed	0
TOTAL NO. CORE BOXES	3
TOTAL CORE RECOVERY FOR BORING (%)	97
CLIENT	Stone and Webster Engineering Corporation
PROJECT	Superconducting Super Collider
LOCATION	NE 1/4, SE 1/4, SE 1/4, Section 4 T2N, R22E
ELEVATION: TOP OF HOLE	4040*
GROUNDWATER	Not Measured
THICKNESS OF OVERBURDEN, FT.	20.4
DEPTH DRILLED INTO ROCK, FT.	29.6
TOTAL DEPTH OF HOLE, FT.	50.0
STARTED	6/09/87
COMPLETED	6/09/87
DRILLED BY	B. Krueger
LOGGED BY	R. Dombrouski

REMARKS

*Elevation interpolated from topographic map

**Uniaxial compressive strength (Qu), psi

DEPTH, FT.	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	BLOWS/FOOT	GEOMECHANICAL: DEGREE OF WEATHERING	JOINTS/FT	DISCONTINUITIES: TYPE	DISCONTINUITIES: DIP
0.0									
0.1	TOPSOIL with Organic Material								
	Sandy Lean CLAY; stiff, moist, medium plasticity, fine grained sand, brown (CL).			10.0 - 11.5	15				
10.0									
12.8	Clayey SAND with Gravel; dense, moist, low plastic fines, fine grained, sandstone, claystone and chert fragments, thinly bedded, brown (SC).			15.0 - 16.5	36 90				
20.4				20.0 - 21.5					
	Interbedded SANDSTONE and CLAYSTONE; light to dark gray, predominantly claystone with 1/2" to 3" thick sandstone beds, thinly bedded, soft rock, Claggett Formation.	89	0	21.5 - 27.0	BROKEN ROCK				
			7125 psi			SW	10	CJ	30°
30.0	Joint set between 30.5 to 31.5					MW	3	FJ CALCITE	70°
		99	78	27.0 - 37.0		MW	3	CJ	35°
	Breaks along bedding planes.								
40.0									

NET 122D

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 5 SHEET 2 OF 2

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	GEOMECHANICAL: JOINTS/FT	GEOMECHANICAL: DISCONTINUITIES TYPE	GEOMECHANICAL: DISCONTINUITIES DIP
40		Interbedded SANDSTONE AND CLAYSTONE; light to dark gray, predominantly claystone with 1/2" to 3" thick sandstone beds, thinly bedded, soft rock, Claggett Formation.	100	96	37.0 - 43.0				
				1910 psi					
			200	91	43.0 - 50.0	F	2	BJ	5°
50.0		Bottom of Hole							

NET 122E

Northern Engineering and Testing, Inc.

LOG OF EXPLORATION BORING

JOB NO. 87-544

HOLE NO. 6

SHEET 1 OF 2

DRILL TYPE: SOIL ROCK Mobile B-53	CLIENT Stone and Webster Engineering Corporation
SIZE, TYPE OF BIT NQ Core Barrel and 2-15/16" Tricone Rock Bit	PROJECT Superconducting Super Collider
CASING: SIZE NW LENGTH 15'	LOCATION NW 1/4, NE 1/4, NE 1/4, Section 11 T2N, R24E
TOTAL NO. OF OVERBURDEN SAMPLES TAKEN 0	
Disturbed 0 / Undisturbed 0	ELEVATION: TOP OF HOLE 3790* / GROUNDWATER Not Encountered
TOTAL NO. CORE BOXES 2 / TOTAL CORE RECOVERY FOR BORING (%) 92	THICKNESS OF OVERBURDEN, FT. 12.0 / DEPTH DRILLED INTO ROCK, FT. 63.0 / TOTAL DEPTH OF HOLE, FT. 75.0
REMARKS *Elevation interpolated from topographic map **Uniaxial compressive strength (Qu), psi	STARTED 6/16/87 / COMPLETED 6/17/87 DRILLED BY B. Krueger LOGGED BY W. Henning

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	JOINTS/FT	DISCONTINUITIES: TYPE	DISCONTINUITIES: DIP
0		Lean CLAY; stiff, moist, medium to high plasticity, salts, light brown (CL).							
10									
12.0		CLAYSTONE; light brown to dark gray, thinly bedded, soft rock, highly weathered, blocky structure, gypsum crystals, rock ravels upon drying, Bearpaw Shale.							
20									
30						MW	5	CJ/OX	80°
		Numerous close spaced joints between 30.0 to 34.0 feet. Joints are closed, moderately weathered and slightly oxidized.	90	40	30.0 - 40.0	SW	5	CJ	45°
40									

NET 122D

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 6 SHEET 2 OF 2

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD / Qu**	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	JOINTS/FT	DISCONTINUITIES: TYPE	DISCONTINUITIES: DIP
40		CLAYSTONE; light brown to dark gray, thinly bedded, soft rock, highly weathered, blocky structure, gypsum crystals, rock ravels upon drying, Bearpaw Shale.							
50			93	83 643 psi 803 psi	50.0 - 56.0	SW	2	CJ	85°
60									
70		Claystone competency increases below 70.0 feet.							
75.0		Bottom of Hole							

NET 122E

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LOG OF EXPLORATION BORING

JOB NO. 87-544

HOLE NO. 7

SHEET 1 OF 1

DRILL TYPE: SOIL / ROCK: Mobile B-53	CLIENT: Stone & Webster Engineering Corporation
SIZE, TYPE OF BIT: Hollowstem Augers	PROJECT: Superconducting Super Collider
CASING: SIZE / LENGTH	LOCATION: Northwest corner, Section 33, T5N, R24E
TOTAL NO. OF OVERBURDEN SAMPLES TAKEN: 1	
Disturbed: 1 / Undisturbed: 0	ELEVATION: TOP OF HOLE: 3800* / GROUNDWATER: 3788
TOTAL NO. CORE BOXES: 0 / TOTAL CORE RECOVERY FOR BORING (%): 0	THICKNESS OF OVERBURDEN, FT.: 9.5 / DEPTH DRILLED INTO ROCK, FT.: 5.0 / TOTAL DEPTH OF HOLE, FT.: 15.0
REMARKS: *Elevation interpolated from topographic map	STARTED: 6/18/87 / COMPLETED: 6/18/87
	DRILLED BY: B. Krueger
	LOGGED BY: W. Henning

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	R.Q.D.	DEPTH, FEET	BLOWS/FOOT
0.1		Fat CLAY; very stiff, moist, high plasticity, blocky structure, gray (CH).				
.5		CLAYSTONE; green gray, soft rock, thinly bedded, moderately weathered,				
12.0		GWL (6/18/87)				
		Hell Creek/Tullock Formation.				
15.0		Bottom of Hole			13.5 - 15.0	31

NET 122D

Northern Engineering and Testing, Inc.

LOG OF EXPLORATION BORING

JOB NO. 87-544

HOLE NO. 8

SHEET 1 OF 3

DRILL TYPE: SOIL / ROCK: Mobile B-53	CLIENT: Stone & Webster Engineering Corporation
SIZE, TYPE OF BIT: 2-15/16" Tricone Rock Bit	PROJECT: Superconducting Super Collider
CASING: SIZE NW LENGTH 35'	LOCATION: NE1/4, NE1/4, Section 6, T5N, R24E
TOTAL NO. OF OVERBURDEN SAMPLES TAKEN: Disturbed 0; Undisturbed 0	ELEVATION: TOP OF HOLE 3865*
TOTAL NO. CORE BOXES 3	TOTAL CORE RECOVERY FOR BORING (%) 93
	GROUNDWATER: See Remarks
THICKNESS OF OVERBURDEN, FT. 2.0	DEPTH DRILLED INTO ROCK, FT. 148.0
TOTAL DEPTH OF HOLE, FT. 150.0	
STARTED 7/28/87	COMPLETED 7/31/87
DRILLED BY C. Nelson	
LOGGED BY W. Henning	

REMARKS *Elevation interpolated from topographic map. Water level not determined; hole tight enough to maintain circulation water at top of hole.

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	R.Q.D.	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	JOINTS/FT	DISCONTINUITIES: TYPE	DISCONTINUITIES: DIP
0									
2.0		Lean CLAY; very stiff, slightly moist, medium plasticity, light brown (CL).							
		Interbedded CLAYSTONE and SANDSTONE; gray, predominantly claystone with sandstone layers, poorly cemented, soft rock, very fine grained sandstone, Hell Creek/Tullock Formation.							
10									
20									
30						SW	2	CJ OX	28°
		Sandstone layers between 31.8' to 33.6' and 38.8' to 40.0'.	84	72	30.0 - 40.0	SW	1	CJ	75°

NET 122D

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 8 SHEET 2 OF 3

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	GEOMECHANICAL: JOINTS/FT	GEOMECHANICAL: DISCONTINUITIES TYPE	GEOMECHANICAL: DISCONTINUITIES DIP
40		Interbedded CLAYSTONE and SANDSTONE; gray, predominantly claystone with sandstone layers, poorly cemented, soft rock, very fine grained sandstone, Hell Creek/Tullock Formation.							
50									
55.0									
60									
70									
80		Argillaceous SANDSTONE; light to dark gray, very fine to fine grained, moderately to well cemented, occasional interbedded claystone seams, breaks appear drilling induced, Hell Creek/Tullock Formation.	100	91	80.0 - 90.0	SW	1	OJ	2°
		Carbonaceous CLAYSTONE between 86.7' to 88.4'							
90		Carbon Detritus at 94.0'							

NET 122E

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 8 SHEET 3 OF 3

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	GEOMECHANICAL: JOINTS/FT	GEOMECHANICAL: DISCONTINUITIES TYPE	GEOMECHANICAL: DISCONTINUITIES DIP
95		Argillaceous SANDSTONE; light to dark gray, very fine to fine grained, moderately to well cemented, occasional interbedded claystone seams, breaks appear drilling induced, Hell Creek/Tullock Formation.							
105		Rock competency increases below 109'.							
115									
						MW	1	BJ clay	3°
125			96	92	120.0 - 130.0	SW	1	CJ	82°
						SW	1	CJ	17°
135		In-place Permeability Test Results Depth, ft. — Permeability, cm/sec. 32.0 - 40.0 — less than 10^{-6} 82.0 - 90.0 — less than 10^{-6}							
145									
150		Bottom of Hole							

NET 122E

Northern Engineering and Testing, Inc.

LOG OF EXPLORATION BORING

JOB NO. 87-544

HOLE NO. 9

SHEET 1 OF 3

DRILL TYPE: SOIL / ROCK	Mobile B-53
SIZE, TYPE OF BIT	NQ Core Barrel 2-15/16" Tricone Rock Bit
CASING: SIZE **	LENGTH 40'
TOTAL NO. OF OVERBURDEN SAMPLES TAKEN	2
Disturbed 2	Undisturbed 0
TOTAL NO. CORE BOXES 3	TOTAL CORE RECOVERY FOR BORING (%) 92
REMARKS	*Interpolated from contours **Hollowstem Augers
CLIENT	Stone & Webster Engineering Corporation
PROJECT	Superconducting Super Collider
LOCATION	NW1/4, NW1/4, Sec. 31, T3N, R25E
ELEVATION: TOP OF HOLE	3849*
GROUNDWATER	3834
THICKNESS OF OVERBURDEN, FT.	10.3
DEPTH DRILLED INTO ROCK, FT.	104.9
TOTAL DEPTH OF HOLE, FT.	115.2
STARTED	8/01/87
COMPLETED	8/04/87
DRILLED BY	C. Nelson
LOGGED BY	D. Kelley

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	R.Q.D.	DEPTH, FEET	BLOWS/FOOT
0						
0.3		TOPSOIL with Organic Material			2.0 - 3.5	8
		Lean CLAY with Sand; firm to very stiff, moist to very mosit, light brown, medium plasticity, very fine grained sand (CL).			7.0 - 8.5	16
10.3					12.0 - 13.5	33
15.0		GWL (8/01/87)			17.0 - 18.5	92
20		CLAYSTONE; light brown and highly weathered near contact, soft rock, friable, thinly laminated, becoming progressively less weathered with depth. Color changing to gray brown, then gray below 17 feet.			22.0 - 22.8	50/0.3
					27.0 - 27.5	69/0.5
30					32.0 - 32.5	100/0.5
					37.0 - 37.4	150/0.4
40						

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 9 SHEET 2 OF 3

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	JOINTS/FT	DISCONTINUITIES: TYPE	DISCONTINUITIES: DIP
40						SW	1	CJ	80°
			94	75	40.0 - 50.0				
						SW	1	CJ	86°
		CLAYSTONE; dark gray, soft rock, thinly bedded, interbedded sandstone lenses, breaks along bedding planes, predominantly fresh to slightly weathered with occasional thin moderately weathered seams, Bearpaw Formation.				SW	1	CJ	83°
50						SW	2	CJ	84°
						SW	1	CJ	69°
			100	80	50.0 - 60.0				
60						F	1 Broken	CJ Rock	72°
			100	70	60.0 - 64.0				
			83	42	64.0 - 67.0	F	1	CJ	90°
						F	1	CJ	8°
						SW	1	CJ	65°
70						SW	1	CJ	86°
			91	71	67.0 - 76.0				
80		Thin well cemented, fine grained sandstone layers between 80.5' to 82.0'.	95	70	76.0 - 84.0	MW	1	CJ	40°
						SW	2	CJ	75°
						MW	1	OJ	65°
						SW	1	CJ	75°
			93	73	84.0 - 94.0	SW	1	CJ	55°
90						SW	1	CJ	45°
95									

NET 122E

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 9 SHEET 3 OF 3

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	GEOMECHANICAL: JOINTS/FT	GEOMECHANICAL: DISCONTINUITIES TYPE	GEOMECHANICAL: DISCONTINUITIES DIP
95		CLAYSTONE; medium to dark gray, moderately hard rock, thinly laminated, predominantly fresh to slightly weathered rock with occasional thin, moderately weathered seams.	98	79	94.0 - 103.0	SW	1	CJ	60°
						MW	1	CJ	5°
100						MW	1	CJ	35°
						SW	1	CJ	60°
			99	33	103.0 - 113.2	SW	2	CJ	90°
110									
			70	45	113.2 - 115.2				
115.2		Bottom of Hole							

NET 122E

NATURAL MOISTURE PROFILE OF THE BEARPAW SHALE

Boring Number	Depth in Feet	Classification	Moisture Content, Percent
9	2.0 - 3.5	Lean CLAY with Sand	22
	7.0 - 8.5	Lean CLAY with Sand	26
	12.0 - 13.5	CLAYSTONE	24
	17.0 - 18.5	CLAYSTONE	19
	22.0 - 23.5	CLAYSTONE	22
	27.0 - 27.5	CLAYSTONE	16
	32.0 - 32.5	CLAYSTONE	13
	37.0 - 37.4	CLAYSTONE	19
	42.5 - 43.0	CLAYSTONE	9
	47.6 - 48.0	CLAYSTONE	7
	52.5 - 53.1	CLAYSTONE	8
	58.4 - 59.1	CLAYSTONE	9
	62.7 - 63.3	CLAYSTONE	9
	66.4 - 66.8	CLAYSTONE	10
	73.0 - 73.7	CLAYSTONE	11
	76.0 - 76.7	CLAYSTONE	10
	80.0 - 80.7	CLAYSTONE	9
	85.0 - 85.7	CLAYSTONE	7
	90.0 - 90.6	CLAYSTONE	10
	96.3 - 96.7	CLAYSTONE	11
	100.8 - 101.7	CLAYSTONE	12
	106.1 - 106.7	CLAYSTONE	11
	110.2 - 110.7	CLAYSTONE	10
	114.2 - 114.5	CLAYSTONE	9

Northern Engineering and Testing, Inc.

LOG OF EXPLORATION BORING

JOB NO. 87-544

HOLE NO. 10

SHEET 1 OF 2

DRILL TYPE: SOIL / ROCK Mobile B-53	CLIENT Stone & Webster Engineering Corporation
SIZE, TYPE OF BIT NQ Core Barrel 2-15/16" Tricone Rock Bit, Drag Bit	PROJECT Superconducting Super Collider
CASING: SIZE NW LENGTH 15'	LOCATION SE1/4, SE1/4, Sec. 20, T2N, R24E
TOTAL NO. OF OVERBURDEN SAMPLES TAKEN 0	
Disturbed 0 / Undisturbed 0	ELEVATION: TOP OF HOLE 3933* / GROUNDWATER See Remarks
TOTAL NO. CORE BOXES 2 / TOTAL CORE RECOVERY FOR BORING (%) 97	THICKNESS OF OVERBURDEN, FT. 2.0 / DEPTH DRILLED INTO ROCK, FT. 88.0 / TOTAL DEPTH OF HOLE, FT. 90.0
REMARKS *Elevation interpolated from topographic map. Water level not determined; some loss of circulation water above 60 feet.	STARTED 7/31/87 / COMPLETED 8/01/87
	DRILLED BY C. Nelson
	LOGGED BY D. Kelley

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	R.Q.D.	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	JOINTS/FT	DISCONTINUITIES: TYPE	DISCONTINUITIES: DIP
0		Silty SAND; medium dense, slightly moist, low plasticity to granular non-plastic, medium brown (SM).							
2.0		SANDSTONE; light gray, mdedium grained, moderately cemented, interbedded claystone lenses, Judith River Formation.							
10									
20		Grading to Argillaceous SANDSTONE below 20 feet with claystone interbeds; light to dark gray, fine grained, well cemented, cross bedded, claystone lenses 1/16 to 8" thick spaced 1/8" to 1" apart, breaks along bedding planes, Judith River Formation.	95	57	20.0 - 30.0	MW	2	CJ	88°
30									
40									

NET 122D

LOG OF EXPLORATION BORING

JOB NO. 87-544 HOLE NO. 10 SHEET 2 OF 2

DEPTH, FT.	LEGEND	CLASSIFICATION OF MATERIALS	% CORE RECOVERY	RQD	DEPTH, FEET	GEOMECHANICAL: DEGREE OF WEATHERING	GEOMECHANICAL: JOINTS/FT	GEOMECHANICAL: DISCONTINUITIES: TYPE	GEOMECHANICAL: DISCONTINUITIES: DIP
40									
50		Argillaceous SANDSTONE with Claystone interbeds; light to dark gray, fine grained, well cemented, cross bedded, claystone lenses 1/16 to 8" thick spaced 1/8" to 1" apart, breaks along bedding planes, Judith River Formation.							
60			100	87	60.0 - 70.0	SW	0	BJ	3°
70									
80		In-Place Permeability Test Results Depth, ft. — Permeability, cm/sec 22.0 - 30.0 — 3×10^{-4} 62.0 - 70.0 — less than 10^{-6}							
90		Bottom of Hole							

NET 122E

MOUNTAIN STATES ANALYTICAL

ANALYTICAL REPORT

June 24, 1987
Job No: 87-911-6
Sheet No. 1 of 2
Invoice No. 870624-04

NORTHERN ENGINEERING AND TESTING, INC.
ATTN: MR. ROGER BRAUN
P O BOX 4699
HELENA MT 59601

Report of: Water Analysis - Superconducting Super Collider

Sample Identification:

On June 18, 1987, these water samples were delivered to our laboratory for analysis. Tests were conducted in accordance with the U.S. Environmental Protection Agency Manual EPA 600/4-79-020, "Methods for Chemical Analysis of Water and Wastes." The results of the analysis are shown on the following page.

Reviewed by _____

rmr

Mountain States Analytical, Inc.

WATER ANALYSIS
SUPERCONDUCTING SUPER COLLIDER

June 24, 1987
Job No. 87-911-6
Sheet 2 of 2

Lab No.:	89788	89789	89790*	89791
Sample No.:	SCC-1	SCC-2	SCC-3	SCC-4
Location:	E. Schmidt	D. Schmidt	R. Conover	Town of Broadview
Formation:	Lennep and Hell Creek	Lennep and Hell Creek	Judith River	Eagle
Total Dissolved Solids (at 180°C), mg/l	2820	1120	1870	1300
Total Hardness ($CaCO_3$), mg/l	1150	507	955	<6
Calcium (Ca), mg/l	220	86	140	<1
Magnesium (Mg), mg/l	146	71	147	<1
Sodium (Na), mg/l	400	244	154	586
Potassium (K), mg/l	8	3	18	1
Bicarbonate Alkalinity (HCO_3), mg/l	342	337	626	548
Chloride (Cl), mg/l	242	96	60	50
Sulfate (SO_4), mg/l	1380	600	791	690

A < sign indicates less than the reported value was present in the sample.

*Duplicate analysis of cations-anions indicates accurate analysis; however, the cation-anion difference is greater than five percent.

BIBLIOGRAPHY

Algermissen, S.T. and Perkins, D.M., 1977, Earthquake-hazard map of the United States. Earthquake Information Bull., 9: 20-21.

Alpha, A.G., and Fanshawe, J.R., 1954, Tectonics of northern Bighorn Basin area and adjacent south-central Montana: Billings Geological Society Field Conference Guidebook, p. 72-85.

Barton, N., Lien, R. and Lunde, J., 1974, Engineering classification of rock masses for the design of tunnel support. Rock Mech., 6: 189-236.

Barton, N., 1976, Recent experiences with the Q-system of tunnel support design. Proc. Symp. on Exploration for Rock Engineering, Johannesburg, vol. 1, 107-117.

Berg, R.B., 1969, Bentonite in Montana: Montana Bureau of Mines and Geology, Bulletin 74, 34 p.

Bergantino, R.N., Sholes, B.C., and Schofield, J., 1985, Quality of ground water in Montana: Montana Bureau of Mines and Geology, Open File Report MBMG 154, scale 1:1,000,000.

Bieniawski, Z.T., 1976. Rock mass classification in rock engineering. Proc. Symp. on Exploration for Rock Engineering. Johannesburg, vol. 1, 97-106.

Bienawski, Z.T., 1974. Geomechanics classification of rock masses and its application in tunnelling. Proc. Third Int. Congr. on Rock Mech., Int. Soc. for Rock Mech., Denver, vol. IIA, 27-36.

Bowen, C.F., 1918, Anticlines in a part of the Musselshell Valley: United States Geological Survey Bulletin 691-F, p. 185-209.

Chamberlin, R.T., 1919, A peculiar belt of oblique faulting: Journal of Geology, v. 27, p. 602-613.

Custer, S.G., 1977, Ground water and soil nitrate one year after cultivation in Hailstone Basin near Rapelje, Montana: Montana Water Resources Research Center report no. 87, 17 p.

Custer, S.G., 1976, Shallow ground water salinization in dryland-farm areas of Montana: Montana Water Resources Research Center report no. 79, 214 p.

Dobbin, C.E., and Erdmann, C.E., 1955, Structure contour map of the Montana Plains: United States Geological Survey Oil and Gas Investigations Map OM-178.B, 1:1,000,000.

Ellis, A.J., and Meinzer, O.E., 1924, Ground water in Musselshell and Golden Valley counties, Montana: United States Geological Survey Water Supply Paper 518, 92p.

Feltis, R.D., 1984a, Roundup 1° x 2° quadrangle, central Montana, structure contour map of the top of the Madison Group: Montana Bureau of Mines and Geology, Geologic Map 35, 1 sheet, 1:250,000

Feltis, R.D., 1984b, Billings 1° x 2° quadrangle, south central Montana,structure contour map of the top of the Madison Group: Montana Bureau of Mines and Geology, Geologic map 36, 1 sheet, 1:250,000.

Feltis, R.D., 1982a, Map showing total thickness of the Lakota Formation and equivalent rocks, Montana: United States Geological Survey Water Resources Investigations 82-4026, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982b, Map showing total thickness of the Judith River Formation, Montana: United States Geological Survey Water Resources Investigation 82-4028, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982c, Map showing altitude of the Swift Formation, Montana: United States Geological Survey Water Resources Investigation 82-4029, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982d, Map showing cumulative thickness of sandstone in the Swift Formation, Montana: United States Geological Survey Water Resources Investigations 82-4030, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982e, Map showing total thickness of the Swift Formation, Montana: United States Geological Survey Water Resources Investigations 82-4031, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982f, Map showing cumulative thickness of sandstone in the Eagle Sandstone and Telegraph Creek Formation, Montana: United States Geological Survey Water Resources Investigations 82-4032, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982g, Map showing total thickness of the Eagle Sandstone and Telegraph Creek Formation, Montana: United States Geological Survey Water Resources Investigation 82-4033, 1 sheet 1:1,000,000.

Feltis, R.D., 1982h, Map showing altitude of the top of the Eagle Sandstone, Montana: United States Geological Survey Water Resources Investigations 82-4034, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982i, Map showing cumulative thickness of sandstone in the "Dakota Sandstone", Montana: United States Geological Survey Water Resources Investigations 82 4035, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982j, Map showing altitude of the top of the "Dakota Sandstone", Montana: United States Geological Survey Water Resources Investigations 82-4036, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982k, Map showing total thickness of the "Dakota Sandstone", Montana: United States Geological Survey Water Resources Investigations 82-4037, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982l, Map showing cumulative thickness of sandstone in the Judith River Formation, Montana: United States Geological Survey Water Resources Investigations 82-4038, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982m, Map showing altitude of the top of the Lakota Formation and equivalent rocks, Montana: United States Geological Survey Water Resources Investigations 82-4039, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982n, Map showing cumulative thickness of sandstone in the Lakota Formation and equivalent rocks. Montana: United States Geological Survey Water Resources Investigations 82-4040, 1 sheet, 1:1,000,000.

Feltis, R.d., 1982o, Map showing altitude of the top of the Fox Hills -Lower Hell Creek aquifer, Montana: United States Geological Survey Water Resources Investigations 82-4041, 1 sheet, 1:1,000,000.

Feltis, R.D., 1982p, Map showing total thickness of the Fox Hills - Lower Hell Creek aquifer, Montana: United States Geological Survey Water Resources Investigations 82-4042, 1 sheet 1:1,000,000.

Feltis, R.D., 1982q, Map showing cumulative thickness of sandstone in the Fox Hills - Lower Hell Creek aquifer, Montana: United States Geological Survey Water Resources Investigations 82-4043, 1 sheet, 1:1,000,000.

Feltis, R.D., 1980, Dissolved solids and ratio maps of water in the Madison Group, Montana: Montana Bureau of Mines and Geology Hydrologic Map 3, 3 sheets, 1:1,000,000.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater, Prentice - Hall, Incorporated, Englewood Cliffs, New Jersey, 604 p.

Gill, J.R., and Cobban, W.A., 1973, Stratigraphy and geologic history of the Montana Group and equivalent rocks, Montana, Wyoming, and North and South Dakota: United States Geological Survey Professional Paper 776, 37 p.

Hall, G.M., and Howard, C.S., 1929, Ground Water in Yellowstone and Treasure counties, Montana: United States Geological Survey Water Supply Paper 599, 118 p.

Hancock, E.T., 1918, Geology and oil and gas prospects of the Lake Basin Field, Montana: United States Geological Survey Bulletin 691-D, p. 101-147.

Hoek, E. and Brown, E.T., 1980, Underground Excavations in Rock. Institution of Mining and Metallurgy, London. Classification of rock masses 14-37.

Hotchkiss, W.R., and Levings, J.F., 1986, Hydrogeology and simulation of water flow in strata above the Bearpaw Shale and equivalents of eastern Montana and northeastern Wyoming: United States Geological Survey, Water Resources Investigation Report 85-4281, 72 p.

Johns, W.M., Straw, W.T., V., Bergantino, R.N., Dressor, H.W., Hendrix, T.E., McClernan, H.G., Palmquist, J.C., and Schmidt, C.J., 1982, Neotectonic features of southern Montana east of 112°30′ west longitude: Montana Bureau of Mines and Geology MBMG-91, 79 p.

Knechtel, M.M., and Patterson, S.H., 1956, Bentonite deposits in marine Cretaceous formations, Hardin District, Montana and Wyoming; United States Geological Survey Bulletin 1023, 116 p.

Lawlor, R.E., 1956, Cretaceous stratigraphy of central Montana: Billings Geological Society Field Conference Guidebook, P. 31-34.

Levings, G.W., 1982a, Potentiometric surface map of water in the Fox Hills - Lower Hell Creek aquifer in the northern Great Plains area of Montana: United States Geological Survey, Open-File Report 82-564, 1 sheet, 1:1,000,000.

Levings, G.W., 1982b, Potentiometric - surface map of water in the Judith River Formation in the northern Great Plains area of Montana: United States Geological Survey Open File Report 82-562, 1 sheet, 1:1,000,000.

Levings, G.W., 1982c, Potentiometric - surface map of the Dakota Formation in the northern Great Plains area of Montana: United States Geological Survey Open File Report 82-563, 1 sheet, 1:1,000,000.

Levings, G.W., 1982d, Potentiometric - surface map of the Fox Hills aquifer of Montana: United States Geological Survey Open File Report 82-564, 1 sheet, 1:1,000,000.

Levings, G.W., 1982e, Potentiometric - surface map of the Eagle Sandstone of Montana: United States Geological Survey Open File Report 82-565, 1 sheet, 1:1,000,000.

Levings, G.W., 1981, Selected hydrogeologic data from the northern Great Plains area of Montana: United States Geological Survey Open-File Report 81-534, 291 p.

Lewis, B.D., Custer, S.G., and Miller, M.R., 1979, Saline - seep development in the Hailstone Basin, Northern Stillwater County, Montana: United States Geological Survey Water Resources Investigations 79-107, 29 p.

Miller, M.R., and Bergantino, R.N., 1983, Distribution of Saline seeps in Montana: Bureau of Mines and Geology Hydrologic Map 7, 7 p., 1 sheet, 1:1,000,000.

Miller, M.R., Bergantino, R.N., Bernal, W.M., Schmidt, F.A., Botz, M.K., Bahls, L.L., and Bahls, P.A., 1980, Regional assessment of the saline-seep problem and a water quality inventory of the Montana plains: Montana Water Resources Research Center report no. 107, 24 p.

Miller, W.R., and Strausz, S.A., 1980, Preliminary map showing freshwater heads for the Mission Canyon and Lodgepole limestones and equivalent rocks of Mississippian age in the northern Great Plains of Montana, North and South Dakota, and Wyoming: United States Geological Survey Water Resources Investigation Open-File map 80-729, 1 sheet, 1:1,000,000.

Montana Bureau of Mines and Geology, 1987, Comanche Basin water quality data print-out: MBMG Ground Water Information Center, 4 p.

Montana Bureau of Mines and Geology, 1980, Summary of Fox Hills, Hell Creek, and Tullock well drilling and aquifer test results: Unpublished departmental report, Billings, MT, 21 p.

Montana Department of Health and Environmental Sciences, 1985, Report on operation and maintenance of water supply (systems--wells): Town of Broadview: Unpublished departmental report, Helena, MT, 3 p.

Montana Department of Natural Resources and Conservation, 1976, Preliminary environment review and report to the Board, Broadview - Alkali Creek 230 kV transmission line: Unpublished departmental report, 21 p.

Montana Department of Natural Resources and Conservation, 1974, Environmental impact statement on the proposed Montana Power Company 230 kV transmission line from Colstrip to Broadview, Montana, Unpublished departmental report, 206 p.

Neibauer, H., 1941, Ground Water in Lake Basin field and adjacent area (Sr. Thesis): Montana School of Mines, Butte, 94 p.; Pl. 8, 1:125,000.

Noble R.A., Bergantino, R.N., Patton, T.W., Sholes, B., Daniel, F., and Schofield, J., 1982, Occurrence and characteristics of ground water in Montana: Montana Bureau of Mines and Geology, MBMG, v.1, Great Plains Region, 82 p.

Northern Engineering and Testing, 1957-1987, various Geotechnical Engineering studies and reports

Norwood, E.E., 1965, Geological history of central and south-central Montana: American Association of Petroleum Geologists Bulletin, V. 49, no. 11, p. 1824-1832

Okamoto, S., 1973, Introduction to Earthquake Engineering, Wiley, N.Y., 571 pp.

Qamar, A.I. and Stickney, M.C., 1983, Montana earthquakes, 1869-1979, historical sensitivity and earthquake hazard: Montana Bureau of Mines and Geology Memoir 51, 79 p.

Reeves, F., 1927, Geology of the Cat Creek and Devils Basin oil fields and adjacent areas in Montana: United States Geological Survey Bulletin 786-B, p. 39-98.

Rioux, R.P., and Dodge, K.A., 1980, Hydrologic data from the Bull Mountains area, south central Montana: United States Geological Survey, Montana Bureau of Mines and Geology, and United States Bureau of Land Management, miscellaneous report, 149 p.

Roberts, A.E., 1972, Cretaceous and early Tertiary depositional and tectonic history of the Livingston area, southwestern Montana: United States Geological Survey Professional Paper 526-C, 120 p.

Ross, C.P., Andrews, D.A., and Witkind, I.J., 1955, Geologic map of Montana: United States Geological Survey, 2 sheets, 1:500,000.

Sales, J.K., 1968, Crustal mechanics of Cordilleran foreland deformation: a regional and scale-model approach: American Association of Petroleum Geologists Bulletin, v. 52, no. 10, p. 2016-2044.

Seed and Idriss, September 1971, Soil Mechanics and Foundations Division, Proceedings of the American Society of Civil Engineers.

Smith, J.G., 1965, Fundamental transcurrent faulting in northern Rocky Mountains: American Association of Petroleum Geologists Bulletin, v. 49, No. 9, p. 1398-1409.

Soil Survey Staff, 1970, Soil Survey of Yellowstone County, United States Department of Agriculture, Soil Conservation Service, 164 sheet, 1:20,000.

Sonnenberg, F.P., 1956, Tectonic patterns of central Montana: Billings Geological Society Field Conference Guidebook, p. 73-81.

Stickney, M.C., and Bartholomew, M.J., In Press, Seismicity and late Quaternary faulting of the northern Basin and Range Province, Montana and Idaho: submitted for August, 1987 publication in the Bulletin of the Seismological Society of America, 32 p.

Thom, W.T., Jr., 1923, The relation of deep-seated faults to the surface structural features of central Montana: American Association of Petroleum Geologists, v. 7, no. 1, p. 1-13.

Thomas, G.E., 1974, Lineament block tectonics: Williston-Blood Creek Basin: American Association of Petroleum Geologists Bulletin v. 58, no. 7, p. 1305-1322.

Uniform Building Code, 1982 Edition, Seismic zone map of the United States

Weigel, R.L. (editor), 1970, Earthquake Engineering. Prentice-Hall, Englewood Cliffs, 518 pp.
-Housner, G.W., Chap. 4, Strong ground motion
-Housner, G.W., Chap. 5, Design spectrum

Westinghouse Electric Corporation, Environmental Systems Department, 1973, Colstrip generation and transmission project: unpublished applicant environmental analysis, Westinghouse Electric Corporation, East Pittsburgh, PA, 352 p.

Wurden, F.H., and Edwards, W.D., 1956, Road log, first day - Billings to Lewistown: Billings Geological Society Field Conference Guidebook, p. 7-15.

Zimmerman, E.A., 1956, Preliminary report on the geology and ground water resources of part of Mussellshell and Golden Valley counties, Montana: Montana Bureau of Mines and Geology Information Circular 15, 13 p., Pl. 1, 1:126,720.